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CHAPTER 4 Algae in Lakes

Introduction

Algae are the basic food producers in lakes, using the energy of sunlight to change water and carbon dioxide dissolved in the water into substances that animals then use to stay alive, grow, and reproduce. The long chain of life that stretches from algae to large animals, including humans, has been studied intensively, and yet there is still much to learn.

Some algae live by attaching to surfaces such as rocks, docks and large aquatic plants. Others lay on the bottom sediments, and a third group floats freely through the water column. The last group, known as "phytoplankton," often makes the biggest contribution to the volume of algae growing in lakes through the year and is the most studied of the various groups.

The interactions between phytoplankton and the environment within a lake can be quite complex and unpredictable. However, there are some generalizations that can be made about changes in populations through the year and how those relate to seasonal changes in lakes in temperate climates, such as that of the Pacific Northwest. Algae need all the same conditions as land-based plants in order to grow. In addition to the necessary elements for photosynthesis, they need a temperature range to which they are adapted, as well as appropriate concentrations of hydrogen ions (pH) and nutrients, including nitrogen, phosphorus, silica, calcium, magnesium, and iron.

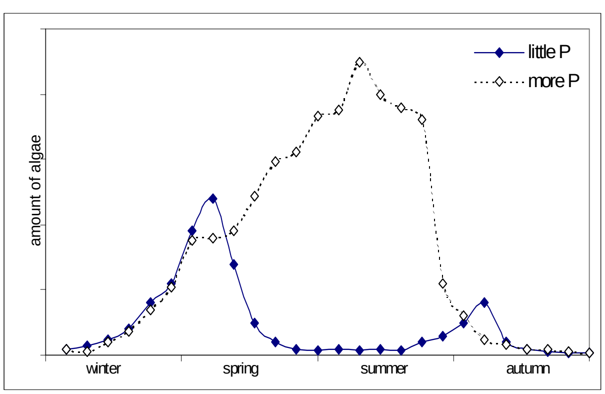
The seasonal interplay between climate, water input and water circulation within a lake result in changes in water temperatures, light availability, and nutrient concentrations in the water. Changing conditions allow different algal groups to become dominant (i.e.: high numbers relative to other algae) as time passes and seasons progress.

While most algae like the warmer temperatures and bright, long days of spring through fall, others can survive in cool temperatures and short days. The general patterns of phytoplankton populations through the seasons ("succession") can be summarized for lakes situated in moderate climate areas like the Pacific Northwest. There are many variations, since each lake is unique. Commonly, phosphorus plays the role of "limiting nutrient" in lakes in the Puget lowlands. A limiting nutrient is the substance necessary for growth that will be exhausted first by the growing algae. When that nutrient is essentially gone from the lake, algal growth will be limited (Fig. 4-1). Algal growth reaches a maximum in spring in lakes with smaller amounts of phosphorus and then drops in summer when the phosphorus has been used up in the epilimnion (upper water). In lakes with more phosphorus, the phytoplankton continue to grow into the summer, reaching maximum levels in July, August, or even September before decreasing temperatures and light begin to limit growth. Sometimes lakes with algal peaks in spring also produce a second peak in fall, when cool temperatures mix the phosphorus from the hypolimnion (lower water) of the lake upwards and enough light enters the water to stimulate the second period of growth.

Chlorophyll and Algae

One simple way to estimate the size of the phytoplankton population in a lake is to measure the amount of chlorophyll *a* found in a liter of water.

Figure 4-1: Illustration of Typical Seasonal Abundance of Algae in Lakes



This figure shows the two general patterns that volumes of algae in a lake can make over a calendar year. The solid line illustrates a common pattern when little phosphorus is available for growth. The dotted lines illustrate what may happen with more phosphorus available.

All algae have chlorophyll, generally contained in special organelles called chloroplasts, since this substance is necessary for photosynthesis (food production). The chlorophyll measurement is sometimes used as an analogue for the volume of phytoplankton present. There are several problems with this method, but it can be a useful tool for classifying lakes in broad terms of productivity.

Algae can have differing amounts of chlorophyll per volume of cell contents, depending on the species present as well as the time of year and the health of the cells. Sometimes quite a large volume of algae will have relatively little chlorophyll and vice versa. For example, the diatoms tend to have less chlorophyll per volume because many have large vacuoles or inclusions inside the cells, which take up space but are not chloroplasts, so do not add to the amount of chlorophyll. Other algae, such as the bluegreens, have pigments in addition to chlorophyll that are used to capture light, so the amount of chlorophyll in each cell may be commensurately less. In addition, as algae age, or senesce, they may lose chlorophyll, so older populations may have less chlorophyll than young, rapidly growing groups.

Since its inception, volunteer monitors for the Lake Stewardship Program routinely collected water during the growing season for chlorophyll *a* analysis, as well as for identification of the most numerous algae present. The chlorophyll data was transformed into TSI values in order to compare it to Secchi transparency and total phosphorus values and to look for regional patterns by summarizing data from all sampled lakes in the area.

Beginning in water year 2000, additional samples were collected for more complete analysis of the phytoplankton populations in the lakes, including not only identification of all the commonly found species, but enumeration and volume estimates as well. A more precise understanding of the processes going on in each lake can be gained by the increased information, in particular the presence or absence of indicator species that could signal major changes in the lake ecosystems.

Major Groups of Phytoplankton

Algae that float in the water of lakes are diverse and come from all the major groups of algae classified by scientists. However, several groups are predominant in this area. Many have something particular about their requirements that can be used to characterize the environment of the lake in which they are found. Lakes with water colored by large amounts of humic substances from adjacent wetlands often feature different phytoplankton species than lakes with clear water, but similar amounts of phosphorus. The following is a description and discussion of the major groups and some representative species of algae that are common in the small lakes of King County. Besides the Latin botanical names of the groups, algae are commonly distinguished by their coloration.

Cyanobacteria: Bluegreen Algae

Bluegreens are simple organisms that share many features with bacteria, but produce food in the same way as plants, thus making their place in biological classifications open to argument. For this reason, some people refer to them as algae although strictly speaking it may not be appropriate. The bluegreens also share many of the environmental requirements of true algae and are important competitors for nutrients and light in the phytoplankton communities of lakes.

Bluegreens can actually be bluish-green in color, but they can also be red, brown, purple, yellow-green and olive. They always have at least a small amount of chlorophyll to complete the photosynthetic reactions, but they also can have a wide variety of other pigments that act as auxiliary light catchers for photosynthesis.

Bluegreens have become especially notorious in lake studies because several species can grow quickly in waters rich in phosphorus, which can be increased by land use changes or other human impacts. On occasion they can outnumber and exclude other naturally occurring species, leading to reduced water clarity, bad smells, and floating scums of decaying colonies, thus adding to their reputation as the algae of polluted waters. In addition, some species are known to release compounds toxic to mammals and fish. Although this is a rare occurrence, when it happens the results are often dramatic and make newspaper headlines.

Bluegreens are most often colonial, which means that the cells band together in groups rather than occur alone in nature. The two major colony forms are simple clusters of cells and cells arranged in long filaments. Some of the filamentous varieties can absorb nitrogen from sources not available to other algae, thus giving them an advantage in lakes where nitrogen may run out before phosphorus. Thus, when the nitrogen to phosphorus ratio is low in a lake, some bluegreens may have the opportunity to grow faster than the other algae present.

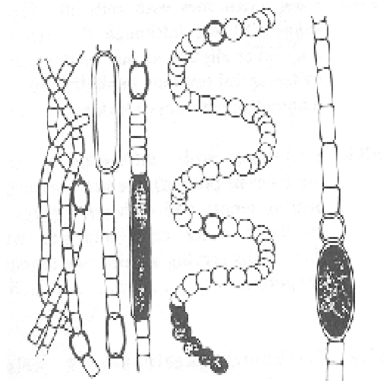
In general, bluegreens do very well in warm water and in high light levels, and therefore are considered to be summer algae. However, several species, such as *Aphanizomenon flos-aquae*, seem to be able to increase their population size in every season of the year in temperate lakes if other conditions are right, and they have been found making significant blooms in fall, winter and spring.

Common bluegreens found in King County lakes include *Aphanizomenon flos-aquae*, *Microcystis aeruginosum* and several species of *Anabaena* (Fig. 4-2). The last two named are most often implicated when toxic blooms are reported, but in fact most occurrences of these species are not toxic and should not cause concerns merely because of their identification in the phytoplankton of a particular lake.

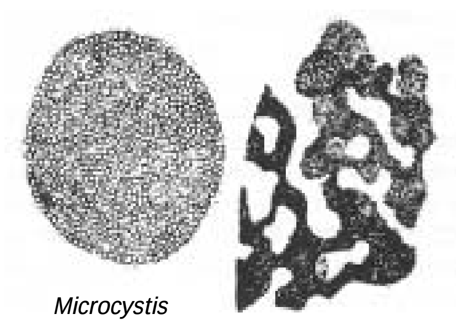
Chrysophytes: Golden Brown Algae

The chrysophyte algae have all the necessary chlorophyll *a*, but also have pigments that give them a characteristic golden to brown color. Many are most common in spring through early summer, although one or two varieties can make large populations in late summer under the right conditions.

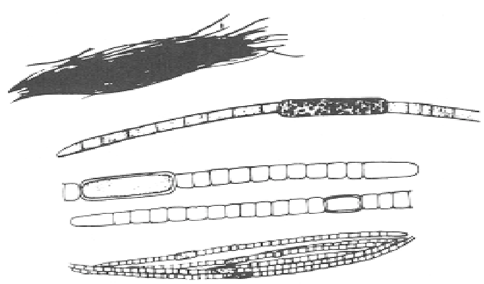
Figure 4-2: Common Bluegreen Algae



Anabaena



Microcystis



Aphanizomenon

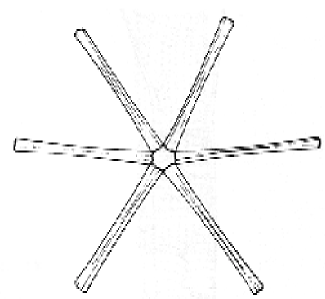
Illustrations obtained from: *How to Know the Freshwater Algae* by G.W. Prescott, 1978.

Diatoms are an important subgroup of the chrysophytes, often dominating spring phytoplankton since they can grow better than other algae in low light and cool temperatures, thus getting a head start on the growing season. Diatoms make hard siliceous coverings for their cells, known as "frustules." This characteristic has two effects: their growth can be limited by the amount of silica present as well as the phosphorus that limits other algae, and the extra weight of the frustule makes it harder for some diatoms to stay in the shallow water where light is most available. Therefore, many diatom populations will be found in spring before the beginning of thermal layering in area lakes, or in fall after it begins to break down, with one or two specific exceptions (see Chapter 1).

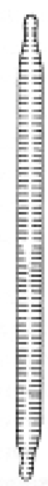
Diatom species can either be found as groups of cells (colonial) or solitary. Typical diatoms found in King County include *Cyclotella* species (solitary) and colonial varieties of *Fragilaria*, and *Asterionella* (Fig. 4-3). Some diatoms, such as several species of *Cyclotella*, have a reputation as indicators of clean water or oligotrophic conditions. Others, such as *Fragilaria*, are known to be more common in mesotrophic lakes.

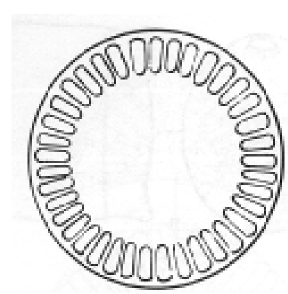
Several other chrysophytes are quite common in lakes of our area. The colonial species *Dinobryon* does not make a frustule, but does make a thin

Figure 4-3: Common Diatom Algae



Asterionella





Cyclotella

Fragilaria

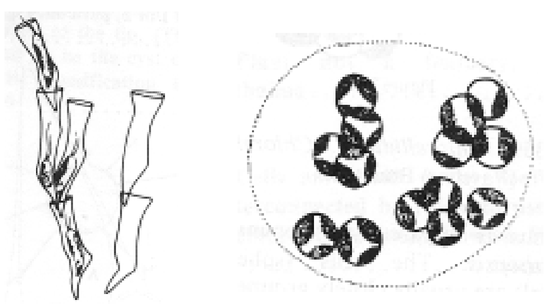
Illustrations obtained from: *How to Know the Freshwater Algae* by G.W. Prescott, 1978.

protective covering shaped like a goblet or drinking glass, termed a "lorica." Individual cells connect to each other in a manner reminiscent of tree branching, and large colonies are more buoyant because of this shape, allowing *Dinobryon* to stay higher in the water column and persist through the summer in many lakes (Fig. 4-4).

Chlorophytes: Green Algae

Green algae produce chlorophyll as their predominant pigment, hence their bright green coloration. They are a large and varied group, with some characteristics closer to the vascular (higher) plants than found in other groups of algae, and therefore some authorities have considered some chloro-

Figure 4-4:
Other Chrysophyte Algae



Dinobryon *Gioeobotrys*

Illustrations obtained from: *How to Know the Freshwater Algae* by G.W. Prescott, 1978.

phytes as evolutionary links to land plants. They can occur in lakes all year, but tend to reproduce and grow much better in warm temperatures and high light levels, thus they generally produce their biggest populations in summer.

Green algae can be solitary or colonial, and both single cells and colonies can take many different shapes from spherical to elaborately geometrical to filamentous. Most of the filamentous green algae grow attached to surfaces rather than floating in the water. Some cells have the means to be mobile, having from one to four whip-like tails called "flagella," which they use to move through the water. Colonial balls of green algae, when each member cell has flagella, can move in characteristic tumbling, rolling motions through the water as all the flagella beat the water. Typical colonial greens found in area lakes include *Volvox* and a rather peculiar large colonial form called *Botryococcus,* which makes large amounts of oils that keep it buoyant through the season (Fig. 4-5). It often turns from green to bright orange as it gets old and dies off, in the same fashion as the changing color of leaves on deciduous trees.

Another specialized group of green algae, called the desmids, are often found in highly colored, acidic waters such as bogs and cool water wetlands. The desmids make a hard cell surface out of an organic material that can have an elaborate shape, ornamented with many spines and knobs. *Cosmarium* is one commonly found in our lakes (Fig. 4-6).

Pyrrhophytes: the Dinoflagellates

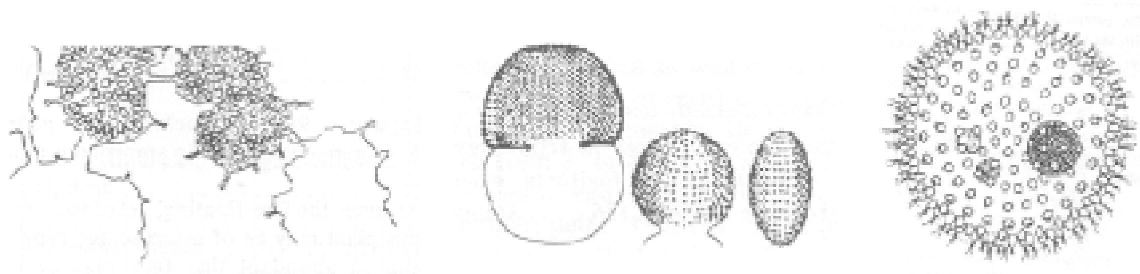
The dinoflagellates are a group that has been characterized both as algae and protozoa because of their ability to move quickly through the water using two flagella. Their movements are vigorous, more characteristic of animals, but the dinoflagellates can also make food like plants. To confuse the issue, they can also ingest other foods as animals do.

Dinoflagellates are nearly always solitary and are common in marine water, where they are notorious for toxic blooms (red tides) that render shellfish poisonous for humans and other animals to eat. Freshwater dinoflagellates are mostly harmless to people, but can color the water red or brown on rare occasions. Large populations will generally occur in the summer, if at all, in our area. The most common forms seen are species of *Peridineum* and *Ceratium*.

Two Lesser Known Groups of Algae

There are two other groups of algae that have no common names, but which are found frequently in the lakes of our region.

Figure 4-5: Common Chlorophyte Algae



Illustrations obtained from: *How to Know the Freshwater Algae* by G.W. Prescott, 1978.

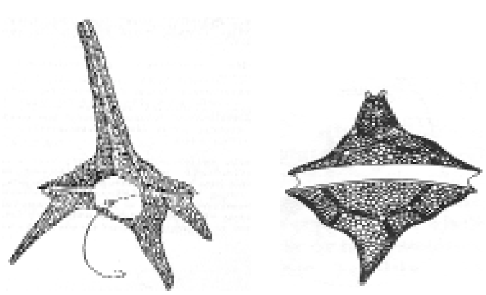
Euglenophytes

Euglena and its allies are often the first algae introduced to students in high school. Its large size and clear structure make it a good subject for beginning biologists to see through a microscope. These algae are always solitary, quite mobile, and generally are found in small bodies of water such as ponds and ditches rather than lakes. However, they have been found in several of the lakes in the Lake Stewardship Program, such as Jones and Paradise. Examples of common euglenoids include *Euglena* and the unusual *Trachelomonas*, which makes an organic shell often colored golden or brown (Fig. 4-7).

Cryptophytes

The cryptophytes are a group of solitary, mobile algae quite distinct from other groups, but with little variation among the species. They are generally small, solitary, and can move quickly using flagella. They are known as an excellent food source for many small planktonic animals. The amount present of these algal species can vary throughout the year, filling in quickly when other algal populations fail to thrive, but disappearing just as fast as the animals graze on them. *Cryptomonas* is a common inhabitant of our lakes (Fig. 4-7).

Figure 4-6: Common Dinoflagellates



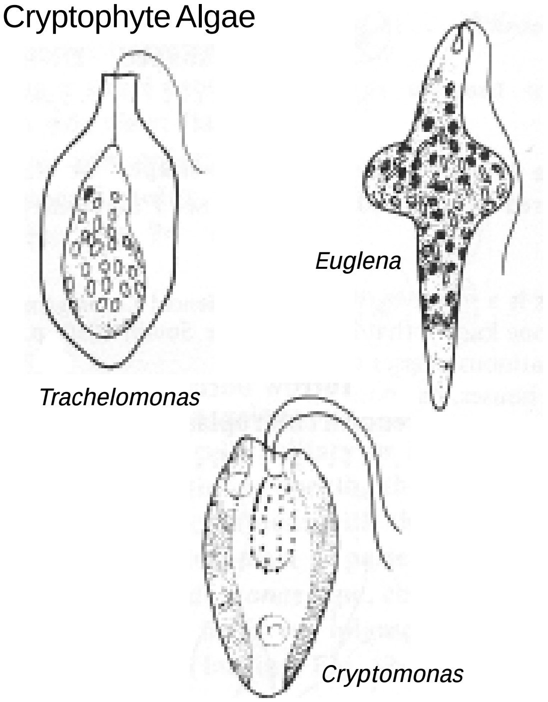
Illustrations obtained from: *How to Know Freshwater Algae* by G.W. Prescott, 1978.

Algae Patterns in County Lakes

Each lake monitored by the Lake Stewardship volunteers has a characteristic suite of algae that do well in its waters. As the patterns of total phytoplankton abundance for any lake will be somewhat different from year to year, following the seasonal changes in light, temperature and nutrients, so the actual species that dominate can also be different, due to the complexities of competition and changing circumstances. The relationships between different groups of algae, the animals that eat them, and the environment are far too complex to make major conclusions based on the sampling protocol of the program. However, the presence of certain species can be taken as indicators of particular conditions, which can be very useful when analyzing the situation of a specific lake. In addition, changes over time may also point to situations that must be considered when looking at management options for a lake.

Summaries of the phytoplankton found in the lakes have been included with individual lake descriptions in Chapter 3. In addition, each lake was also examined for algae distribution through the water

Figure 4-7: Common Euglenophyte and Cryptophyte Algae



Illustrations obtained from: *How to Know the Freshwater Algae* by G.W. Prescott, 1978.

column, concentrating on the possibility of deeper water algae production. Some lakes are clear enough for light to penetrate below the thermocline, and large amounts of algae can continue to grow slowly in the cool temperatures. They are cut off from the surface water, but can use the light to photosynthesize, feeding off the nutrients that are still available in the deep water after the epilimnetic concentrations are exhausted. The two profile measuring events done by the Lake Stewardship Program included a mid-depth phytoplankton sample to look for evidence of differing volumes of algae and changes in species present in the deeper water of each lake (Table 4-1). The phytoplankton communities are reported as dominant groups rather than as individual species.

When the phytoplankton in the deeper water was between 50% to 200% of the volume of the algae at the 1m depth, the values were considered to be essentially similar because of general patterns in variability that are present in the phytoplankton concentrations in many lakes. Lakes in which the profile surveys generally followed this guideline for both dates included Allen, Angle, Beaver 2, Bitter, Boren, Burien, Killarney, Meridian, Mirror, Morton, Neilson (Holm), North, Steel, and Walsh. For most of these lakes, the dominant algae in the shallow samples were also dominant in the deeper samples.

Many lakes differed significantly from this relationship on one or both dates. As an example, in Lake Desire, the phytoplankton in June was 14 times higher in the 1m sample than in the 5m sample, though both samples were dominated by chrysophytes. In August, the volumes had increased at both depths, but the 1m sample contained 6 times more volume than the deeper sample, and an unidentified colonial alga dominated. Other lakes that exhibited much higher volumes in the surface water on both dates included Beaver 1, Fivemile and Kathleen. Lakes with more algae in the 1m sample in June only included Paradise, Pipe, Sawyer, Spring, and Welcome. No lakes had more algae in the 1m sample in August only.

Lakes that exhibited a higher concentration of algae in the deeper sample on both dates included Langlois, Leota, McDonald, Ravensdale, and Shady. Those with more algae in the deeper sample in June only included Lucerne, Marcel, Pine, Retreat, Star, and Wilderness. Those with more algae in the deep water in August only included Ames and Margaret.

Several lakes showed a mixed pattern of higher 1m samples on one date and higher deep sample son the other. These included Cottage, Geneva, Haller and Joy.

There were several cases where cyanobacteria (bluegreens) were the dominant or co-dominant algae in the deeper water, but were not important members of the phytoplankton community at the surface. Lakes where this pattern was found on at least one of the two dates included Ames, Bitter, Desire, Haller, Kathleen, Neilson (Holm), Pipe, Sawyer, and Spring. This does not mean that

Table 4-1: Algae Patterns for 2002

Lake	(m) depth	5/20/02 Volume	Major Groups	9/8/02 Volume	Major Groups
Allen	1	857534	Chlor-Chryso	3001288	Dino
	3.5	1631148	Chryso-Chlor	2020458	Dino
	ratio	0.526		1.485	
Ames	1	3412715	Chryso	664563	Chlor
	7	1726525	Chryso	3026861	Cyan
	ratio	1.977		0.220	
Angle	1	1559694	Chryso-Dino	123472	Dino-Cyan
	8	1604947	Chryso-Chlor	206416	Cyan-Dino
	ratio	0.972		0.598	
Beaver 1	1	709274	Chryso-Cyan	1211596	Chrys
	7	76390	Cyan	243212	Chryso-Chlor
	ratio	9.285		4.982	
Beaver 2	1	930568	Chryso-Cyan	564842	Dino-Cyan
	7	832787	Chryso-Cyan	648478	Chryso
	ratio	1.117		0.871	
Bitter	1	609445	Chlor	2858684	Chlor-Chryso
	8	843851	Chlor	5502569	Cyan
	ratio	0.722		0.520	
Boren	1	352052	Chlor-Crypt	1364249	Cyan-Chlor
	5	518503	Cyan-Chlor	2646241	Cyan
	ratio	0.679		0.516	
Burien	1	1746164	Chryso-Chlor	403577	Cyan-Euglen
	8	1054783	Chlor-Crypt	606749	Euglen-Cryp
	ratio	1.655		0.665	
Cottage	1	9645272	Chlor-Chryso	829340	Cyan
	6.5	576542	Chryso-Cyan	13266508	Cyan
	ratio	16.730		0.063	
Desire	1	10385487	Chryso	26415214	Other
	5	730174	Chryso-Chlor	4162117	Cyan-Other
	ratio	14.223		6.347	
Fivemile	1	2339886	Chryso	953994	Chlor-Dino
	5	224465	Cyan-Chryso	69799	Chryso-Cryp
	ratio	10.424		13.668	
Geneva	1	99431	Crypt-Chlor	2692136	Chryso
	7	339682	Chryso	121607	Euglen-Chlor
	ratio	0.293		22.138	
Haller	1	929559	Chlor	639733	Chrys
	6	144275	Chlor-Crypt	8153423	Cyan
	ratio	6.443		0.078	
Joy	1	2534108	Chryso	133630	Chryso-Crypt
	7	1050287	Chryso	283134	Crypt-Chryso
	ratio	2.413		0.472	
Kathleen	1	230216	Chryso-Chlor	6024935	Chryso
	3	52633	Chryso	1731486	Cyan
	ratio	4.374		3.480	
Killarney	1	831025	Chryso	619239	Chryso-Chlor
	3	1126251	Chryso	534313	Chryso
	ratio	0.738		1.159	
Langlois	1	2399750	Chryso	142285	Chlor-Chryso
	14	5518776	Dino	1718806	Dino
	ratio	0.435		0.083	
Leota	1	33835	Crypt-Chlor	331539	Crypt
	3	160259	Chlor-Crypt	17775790	Dino
	ratio	0.211		0.019	
Lucerne	1	404113	Chryso-Dino	245808	Chryso-Crypt
	6	1299729	Chryso	413670	Crypt-Chryso
	ratio	0.311		0.594	

Lake	(m) depth	5/20/02 Volume	Major Groups	9/8/02 Volume	Major Groups
Marcel	1	1843115	Chryso	384255	Chryso-Euglen
	2	11332085	Chryso	209255	Chryso-Dino
	ratio	0.163		1.836	
Margaret	1	231454	Chryso-Dino	197376	Cyan-Chlor
	5.5	342878	Chryso	1325417	Crypt
	ratio	0.675		0.149	
McDonald	1	1008334	Cyan	302451	Chlor-Euglen
	7	7084520	Cyan	747803	Dino
	ratio	0.142		0.404	
Meridian	1	545111	Chryso-Chlor	316265	Chlor-Chryso
	13	766432	Chryso-Chlor	279675	Chryso-Chlor
	ratio	0.711		1.131	
Mirror	1	925199	Dino-Chryso	830683	Chlor-Chryso
	3.5	1217307	Dino-Chryso	626878	Chlor-Euglen
	ratio	0.760		1.325	
Morton	1	1881349	Chryso	345091	Crypt-Cyan
	3	1751762	Chryso	169484	Crypt-Cyan
	ratio	1.074		2.036	
Neilson (Holm)	1	1352075	Chryso-Chlor	1808892	Chryo-Dino
	4	1404307	Chryso	2294191	Cyan
	ratio	0.963		0.788	
North	1	274456	Chryso-Chlor	1387704	Chryso
	5	425863	Crypt	1019708	Cyan-Euglen
	ratio	0.644		1.361	
Paradise	1	1795424	Crypt	11986224	Chryso
	4	286127	Chryso-Dino	6037508	Chryso
	ratio	6.275		1.985	
Pine	1	544685	Cyan-Chryso	969524	Chryso-Cyan
	6	1428501	Cyan	1105636	Cyan-Chryso
	ratio	0.381		0.877	
Pipe	1	1486469	Chryso	12370101	Chryso
	10	654368	Chryso	8349747	Cyan
	ratio	2.272		1.481	
Ravensdale	1	36036	Crypt	784406	Crypt-Chryso
	8	298332	Crypt	1637849	Chryso-Dino
	ratio	0.121		0.479	
Retreat	1	1183030	Chryso	3051010	Chryso
	8	3550129	Chryso	2636723	Chryso
	ratio	0.333		1.157	
Sawyer	1	4156644	Chryso	330350	Chryso
	8	1207812	Chryso	1103257	Crypt-Cyan
	ratio	3.441		0.299	
Shadow	1	662953	Chryso-Cyan	1106765	Chryso-Cyan
	6	476470	Cyan	6279053	Cyan
	ratio	1.391		0.176	
Shady	1	2986025	Chryso	237541	Crypt-Chryso
	6	7494498	Chryso	922773	Chryso-Dino
	ratio	0.398		0.257	
Spring (Otter)	1	748947	Chryso	1055135	Chryso
	4	198296	Chryso	703577	Chryso-Cyan
	ratio	3.777		1.500	
Star	1	1316296	Chryso	324131	Chryso
	7	3547757	Chryso	302915	Chryso-Chlor
	ratio	0.371		1.070	
Steel	1	642099	Chryso-Chlor	693225	Chryso-Dino
	4	963494	Chryso	652338	Dino-Chryso
	ratio	0.666		1.063	

Table 4-1: Algae Patterns for 2002 (continued)

Lake	(m) depth	5/20/02 Volume	Major Groups	9/8/02 Volume	Major Groups
Trout	1	1131469	Cryp-Chlor	1067119	Chlor
	4	243002	Crypt	779647	Chrys-Cyan
	ratio	4.656		1.369	
Twelve	1	604568	Chrys	713422	Cyan
	4	38020	Chlor-Euglen	592102	Cyan
	ratio	15.901		1.205	
Walsh	1	2083274	Chryso	507311	Chlor-Chryso
	2	3946507	Chryso	479411	Chryso-Cyan
	ratio	0.528		1.058	
Welcome	1	1559683	Chryso	135254	Dino-Chryso
	2	131918	Chryso-Crypt	230718	Cyan
	ratio	11.823		0.586	
Wilderness	1	1770182	Chlor	2124130	Chryso
	5	4623971	Chlor	3462145	Chryso
	ratio	0.383		0.614	

bluegreens constitute a problem in these lakes, but does point out that surface samples alone may not always completely characterize the various phytoplankton that are present. By extension, it should also be kept in mind that, although very unlikely, lakes with this pattern do have the potential to host toxic blooms that have little or no representation in the surface water of the lake and so might not be readily detected.

It is difficult to draw regional conclusions from the various vertical patterns of phytoplankton distribution in King County lakes, although the pattern found at specific lakes should be helpful in putting together an integrated picture of that particular ecosystem. In lakes where algae in the surface water greatly outnumber the algae at depth, the surface population could be interfering with light transmission to the deeper water, thus limiting growth in the deep water by light availability instead of by nutrients (the “shading effect”). Lakes with water colored by humic acids may also have deep water light limitations. The outcome of shading or blocked light transmission is that nutrients in the deep water are not utilized during the summer months and will be mixed throughout the water in the fall, causing increased growth as the water cools. This pattern can be seen in many county lakes and may contribute to the fall and winter blooms of the bluegreen species *Aphanizomenon* reported for several county lakes, including Beaver, Boren, Cottage, Desire, Geneva, McDonald, Pine, Shadow, Trout, and Wilderness.

In contrast, situations where algae in the deep water outnumber surface algae imply that water conditions allow sufficient light for algae growth to occur in deep water. Nutrients are usually in higher concentrations in the hypolimnion during summer when stratification inhibits water mixing. They are sometimes even replenished by chemical releases from the sediments. It should be noted that since a by-product of photosynthesis is the release of oxygen, deep-water algae growth could actually result in a decreased rate of nutrient recycling in some lakes.

Lakes with little or no stratification may have more homogeneous vertical distribution patterns of phytoplankton to match the homogeneous temperatures and nutrient concentrations, but this is not always true. Even if the water is the same temperature from top to bottom, the depth of light penetration in lakes with low transparencies can result in higher growth rates and larger populations of algae in the surface water.

Looking at the conditions of light penetration, water temperature, nutrient concentrations and the patterns of algae population growth may produce a great deal of insight into the important factors operating at a particular lake. However, there are situations where another unknown factor appears to be operating. In such cases, analyzing the community of animals that graze upon the algae, or even the animals that prey upon the grazers, can provide interesting links that might otherwise remain mysterious.

CHAPTER 5
Discussion

Introduction

Regional water quality patterns found in the lakes of the inhabited areas of King County can be produced by comparing the data from all the lakes in water year 2002, as well as examining data for each lake over time. In addition, because of the wide range in local rainfall received through the year, measuring precipitation at each lake makes it possible to look at particular changes in lake level relative to the rainfall received in that watershed. Level I monitoring data on precipitation, water levels, and Secchi transparency (water clarity) are compared for all the lakes measured in 2002, including Lake Sammamish. The discussion of Level II monitoring covers the similar comparisons for average phosphorus and chlorophyll, Trophic State Indices (TSI), and nitrogen to phosphorus ratios.

Precipitation

While Level I volunteer monitors collected precipitation data at 38 lakes throughout King County in water year 2002, only 23 lakes had comprehensive rainfall records for the period. If the precipitation records for a lake had some gaps, but had data for at least 330 days, estimated values for the missing days were inserted by averaging all available data from the other sites in the county for that day. Discussion of the data set as a whole is limited to the 23 lakes with the most complete data.

Water Year 2002 Precipitation Data

The sum of accumulated rainfall at Sea-Tac International Airport for the 2002 water year totaled 994 millimeters (mm), which is just above the 50-year average of 972mm. This can be visualized by comparing it to the totals of the last four years and to the mean precipitation accumulation rate for the last 50 years at the Sea-Tac weather station (Fig. 5-1). The accumulation rate over the water year mirrors the average very closely, remaining just above it over the entire period. The annual total was a substantial increase over the water year 2001, which was one of the lowest totals on record, but still significantly below the recent high accumulative totals recorded in 1996, 1997, and 1999.

Figure 5-1. Monthly precipitation accumulation over recent water years at Sea-Tac airport.

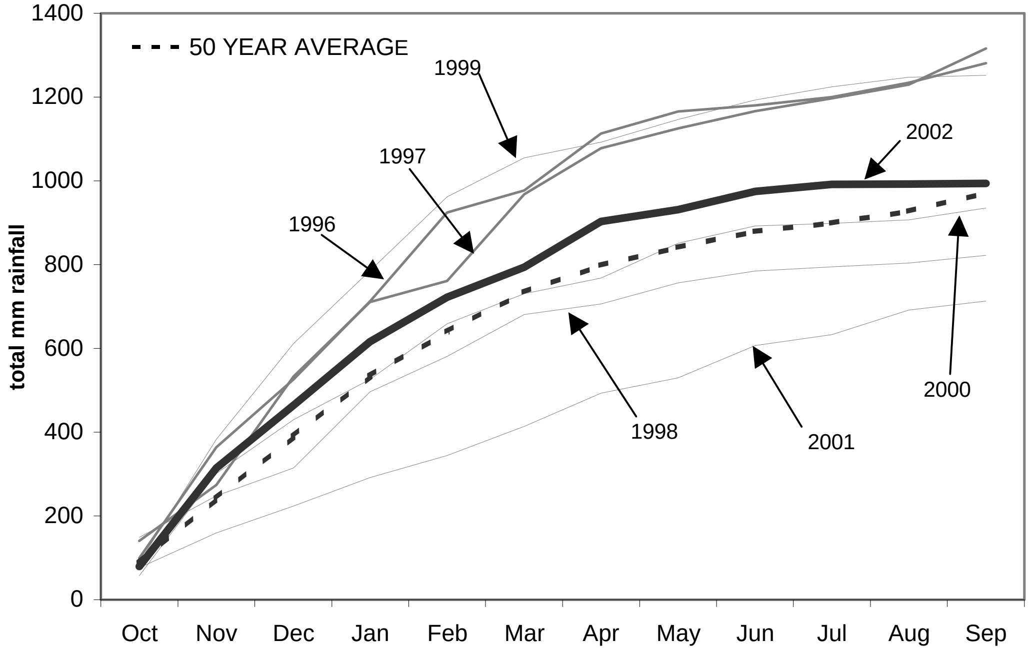
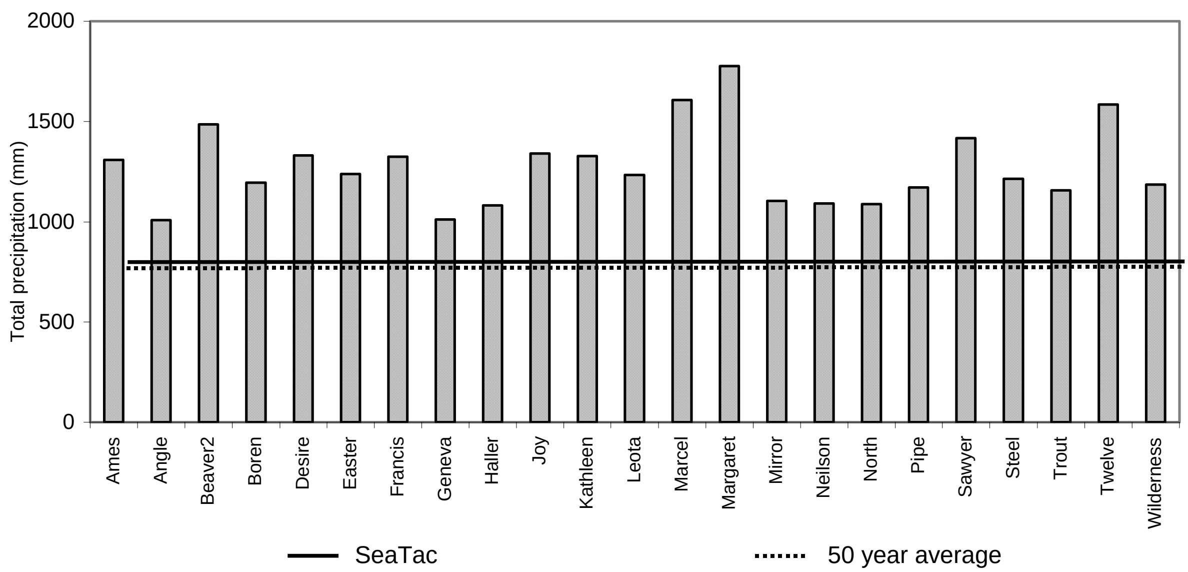
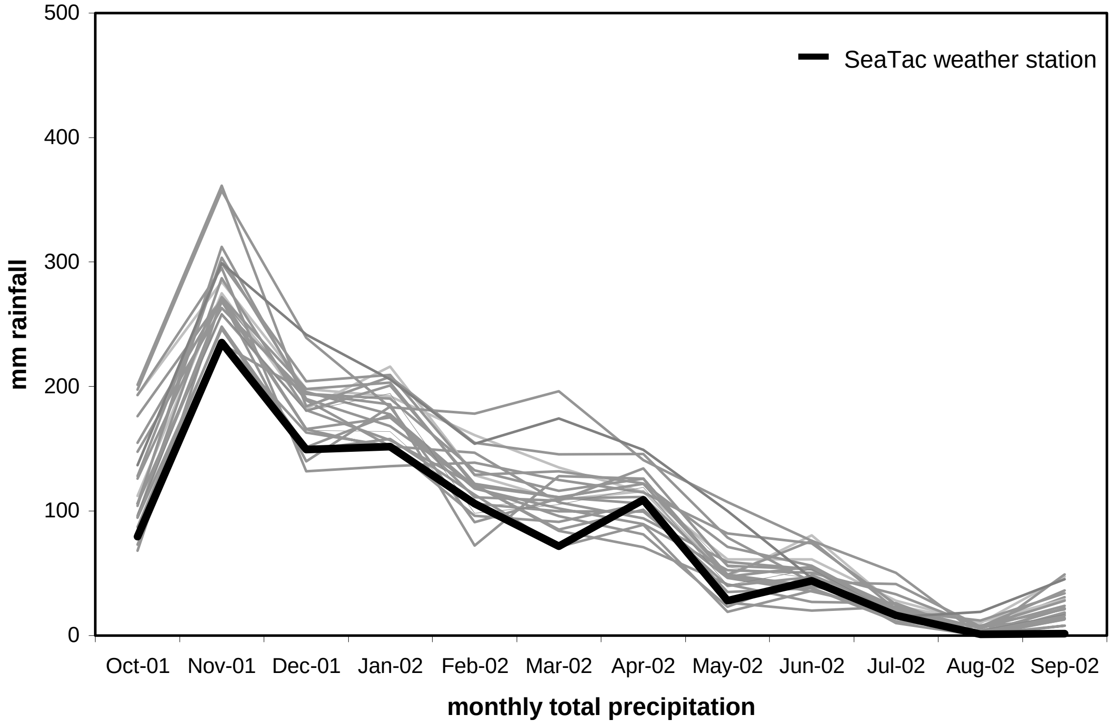


Figure 5-2. Total annual precipitation at individual lakes for WY 2002.



Dotted line refers to 50-year average at Sea-Tac; solid line refers to water year 2002 at Sea-Tac

Figure 5-3: Monthly precipitation at Sea-Tac compared to individual lake stations, WY 2002.



Precipitation totals for water year 2002 for the 23 (Fig. 5-2) show that all the lake sites exceeded the total accumulation recorded at Sea-Tac (solid line). The differences between the various totals recorded at the lake sites illustrate the influence of location on both daily and annual precipitation values. A variety of factors, including rain gauge placement, adherence to protocols, local topography and storm intensity, as well as patterns of cloud movement between Puget Sound and the Cascade Range, influence the precipitation recorded at each location.

If the monthly totals for each lake during the year are plotted together with the Sea-Tac data on a single chart (Fig. 5-3), it becomes clear that the Sea-Tac station usually ranks in the lower range of the monthly precipitation accumulations recorded at all the locations covered by King County volunteers in 2002.

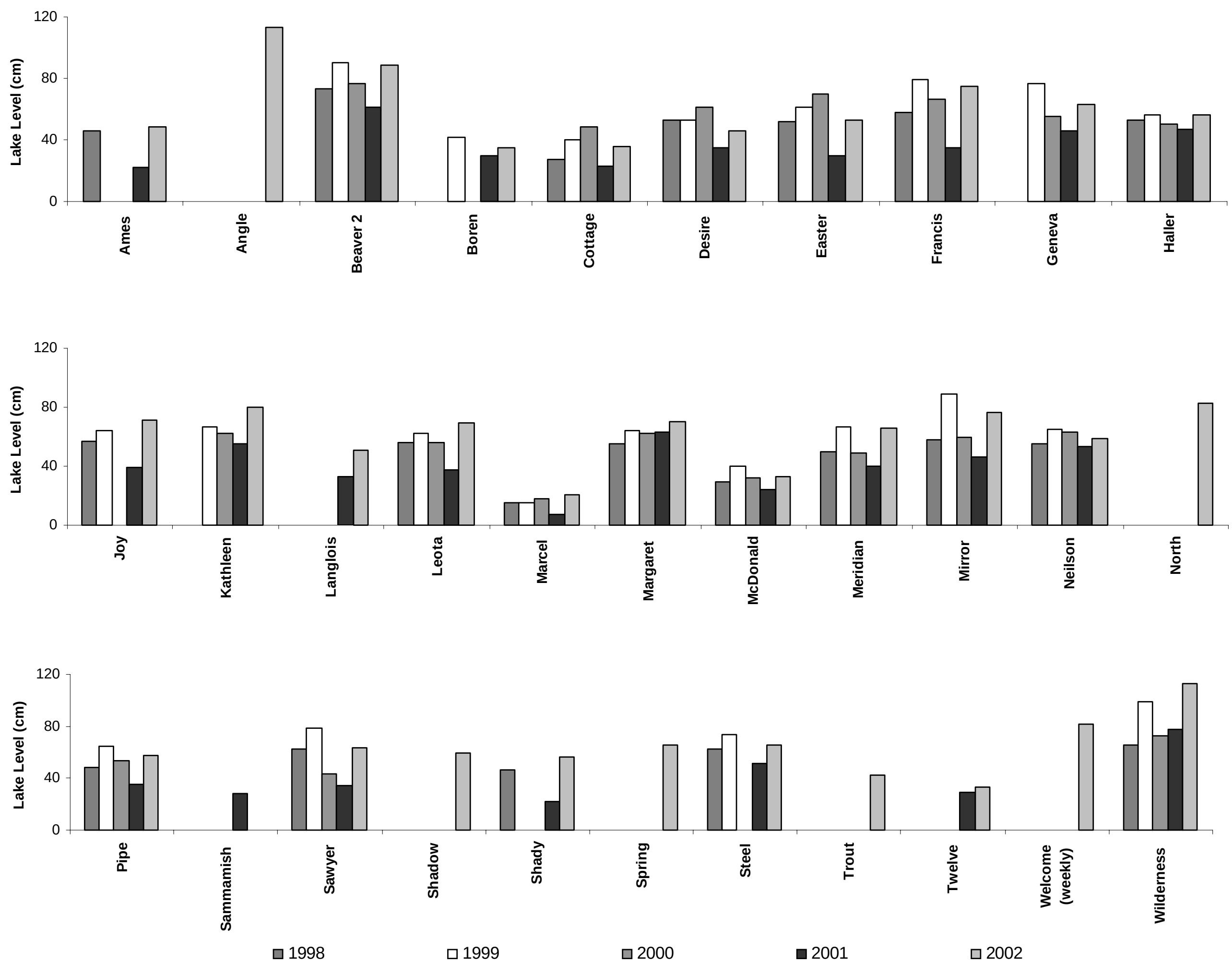
Conclusions

Volunteer monitoring is an invaluable tool for collecting long-term localized precipitation data, allowing for comparisons to be made across the county, as well as establishment of realistic ranges in values. The water year 2002 total at the Sea-Tac weather station was very close to the 50-year average. However, at nearly all of the lake sites, volunteers recorded higher precipitation levels than what was observed at Sea-Tac.

Lake Level

Fluctuations of water level in lakes are affected both directly and indirectly by precipitation. Other major influences include: (1) watershed size (also called the “catchment basin”); (2) land use within the watershed boundaries; (3) vegetation types and coverage; (4) nearby or adjacent wetlands; (5) soil structures and types, as well as specific geology of the area; (6) surface and subterranean hydrology; (7) outlet type or structure, with or without management;

Figure 5-4. Annual range of mean weekly lake level for lakes with complete records, 1998-2002.

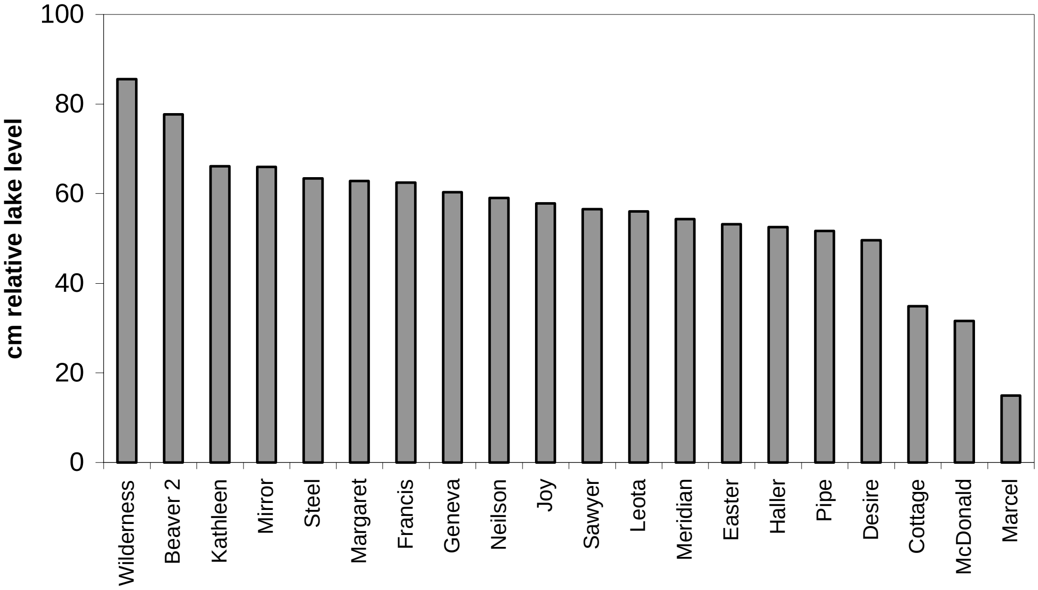


and (8) the volume of water the lake holds relative to the size of the watershed. These factors combine to give each lake a pattern of water level change that is unique.

Nonetheless, some common fluctuation patterns can be found among lakes. In general, lakes in urbanized watersheds commonly respond to precipitation events more quickly and have greater fluctuations in water level than lakes in undeveloped watersheds. This is largely due to the increase in impervious surfaces, as well as the collection and channelization of surface run-off for quick removal from developed properties. Lakes with large watersheds may also respond more slowly to precipitation because of the distance that runoff travels before entering the lake. Lakes with large surface areas or volumes relative to the size of the watershed may be less responsive than other lakes in general because they do not receive very much more water from a storm event than the amount that comes in from direct precipitation.

Sometimes other factors become important in water level changes. Beavers building dams on outlet streams can keep lake levels high through the summer, while human destruction of such dams can cause sudden drops in water

Figure 5-5. Mean range over the last 5 years for lakes with at least 4 years of complete data.



level and unexpected surges of water downstream. Adjustable heights of weirs on outlet streams can also account for unexpected patterns in lake levels.

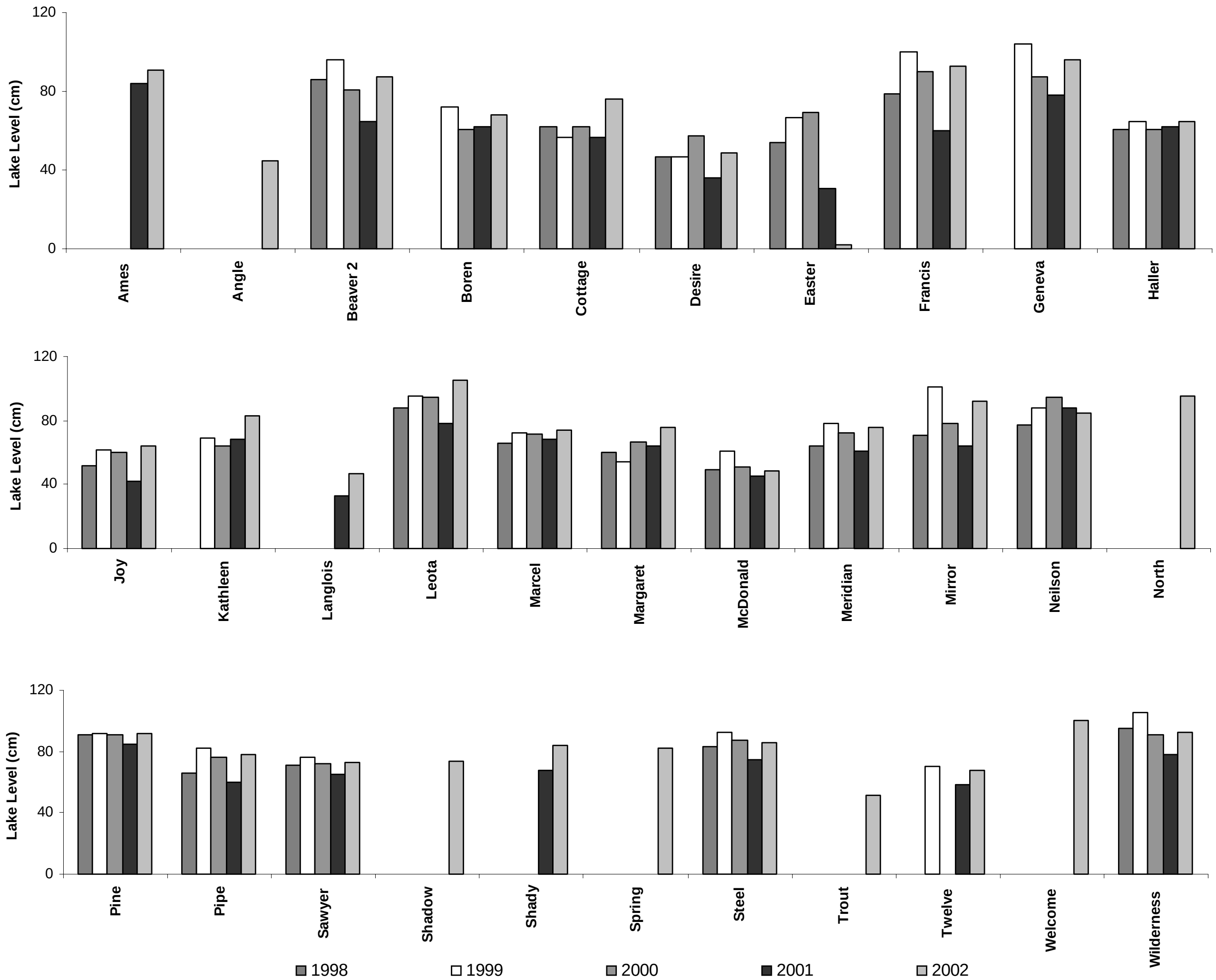
Lake Level Fluctuations 2002

Seasonal fluctuations in lake levels were observed at most lakes with complete precipitation data sets. Water levels were typically at the lowest stand during fall (the end of the water year) and steadily increased during late fall/ early winter as precipitation increased (see Chapter 3 for individual lake results). During the fall and winter, many lakes also showed the greatest fluctuation in daily lake level readings, as storm runoff from watersheds with saturated soils quickly flowed to the lakes instead of percolating through soil horizons. This type of runoff pattern caused peaks in water levels to mirror large precipitation events closely, which can be seen in records for individual lakes (see Chapter 3 text).

The range in water level is the difference between the maximum and minimum stands over the entire water year (Fig. 5-4). Changes in a particular lake from year to year can be compared in addition to comparing the records between lakes. Lakes with large fluctuations show their high sensitivities to winter precipitation and run-off as well as to evaporation through summer. Lakes with small variations in water level probably receive a higher percentage of ground water inputs, which are a steadier source of water through the year than rainfall. Some lakes are managed at the outlet for desired water levels, but this does not necessarily mean that the annual range will be small. For example, Lake Margaret is kept lower in the winter as a buffer against high levels following rainstorms and is allowed to rise to high levels in the spring in order to store water for domestic use by homeowners in the area.

Where essentially complete records were available for comparison, it was noted that lake level ranges in nearly every case were higher than for water year 2001. The recorded annual ranges were close to the highest over the last five years for many of the lakes. The lakes with the widest average fluctuation over the last five years include Wilderness and Beaver 2, followed by Kathleen, Mirror, Steel, Margaret and Francis (Fig. 5-5). While several lakes such as Angle, Killarney, and North had a very wide

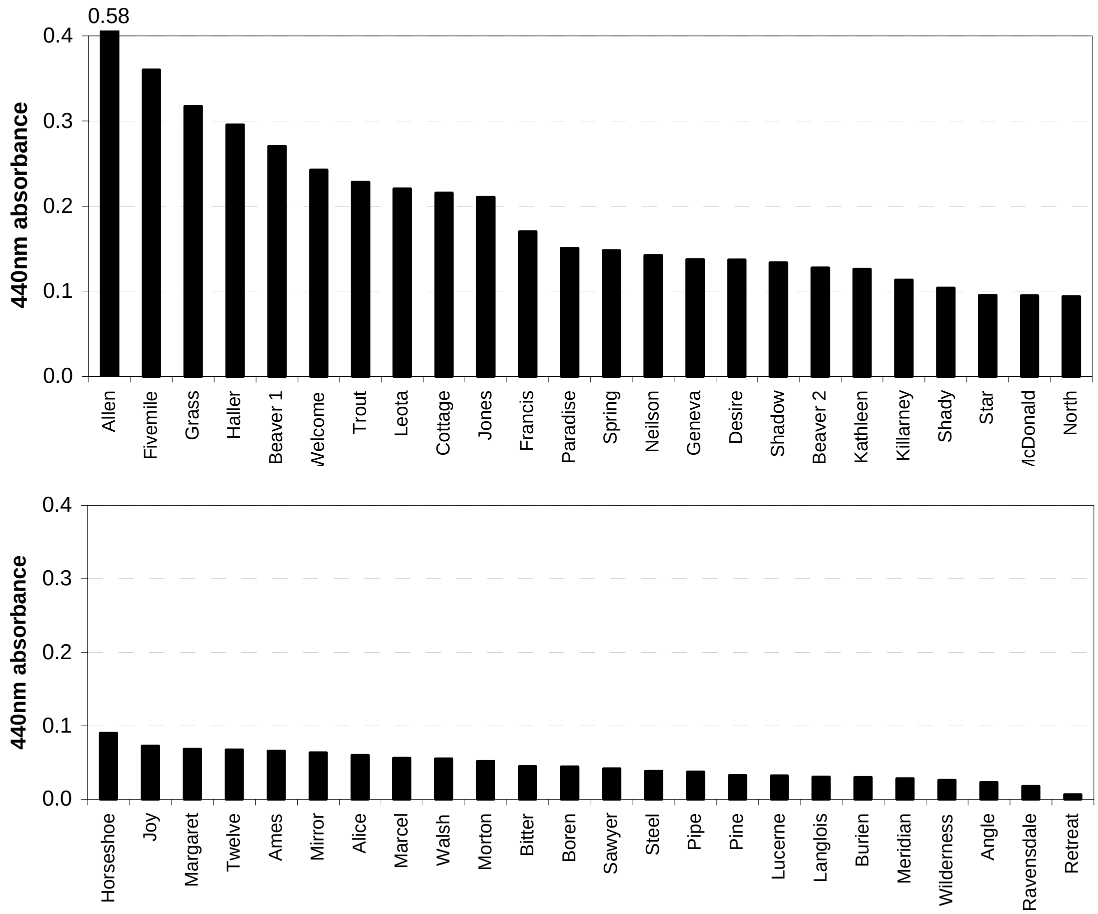
Figure 5-6. Annual maximum water levels recorded from 1998 – 2002.



range of fluctuation in 2002, there were not enough years of record to calculate the average.

Analyzing records of annual maximum high water level can indicate whether or not a lake was at its capacity for water storage (at or above the threshold of the outlet) before the beginning of the dry season each year. It also indicates if a lake rose to unusual heights at any point during the wet season (Fig. 5-6). High water levels cannot be compared from lake to lake because water level measurements for each lake are relative, based on the vertical placement of the fixed meter stick used to make the measurement. However, an idea can be gained of whether or not the lake was at capacity by comparing high precipitation years with low ones; for this report the best years to contrast would be 1999 with 2001. As an example, Haller Lake had a relatively constant maximum level for the last five years, suggesting that inputs were balanced by water flowing out rapidly enough to maintain the winter level at a stable height. On the other hand, Lake Wilderness had much higher stands in 1999 and 2002 than the other three years, suggesting that it may have a rapid response to large rainfall events that can lead to a great deal of fluctuation from year to year. This kind of evidence can give clues regarding the unusually large water level ranges found for many lakes in 1997 and the impacts caused by their respective watersheds.

Figure 5-7. Spectral measurement of water color in June 2002.



Conclusions

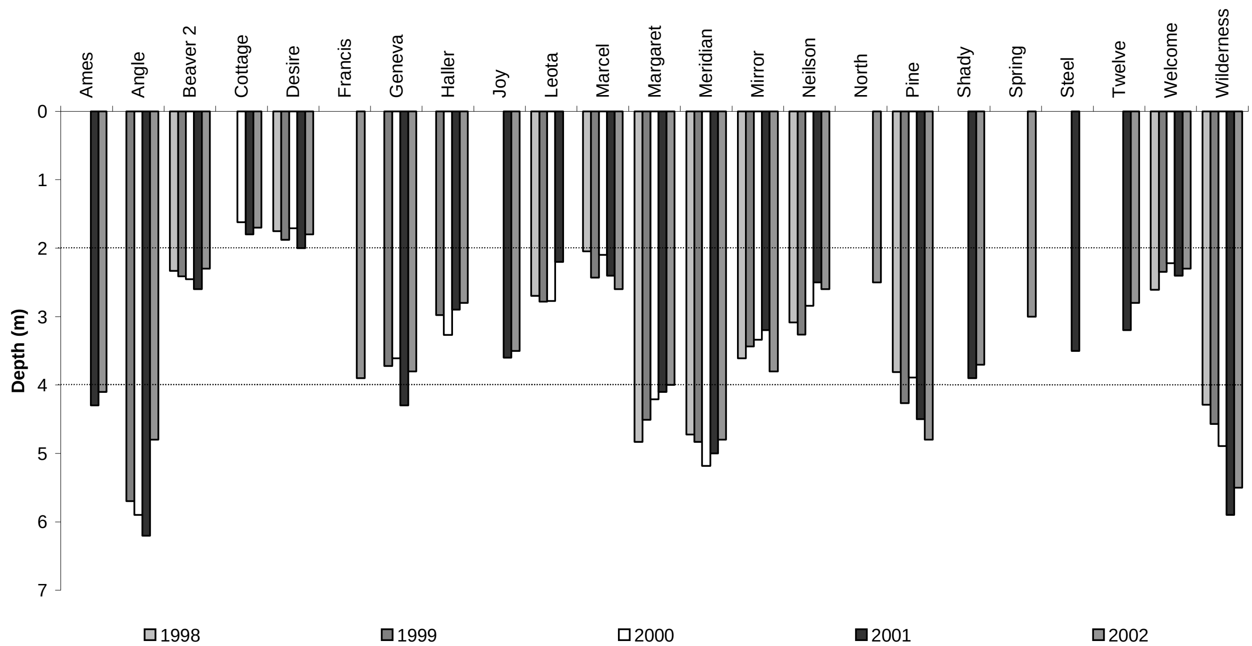
Most volunteers recorded higher lake level fluctuations and maximum stands in 2002 than in 2001. Continued volunteer observation is important for determining how changes in natural conditions, management activities, or watershed development affect individual lake levels. Ongoing monitoring will help lakeside residents, citizens in nearby communities, and city and county officials to understand more thoroughly the trends and relationships of water level fluctuations with precipitation, thus leading to more effective drainage management.

Secchi Transparency

The Secchi depth measures the relative transparency of water to an observer above the lake surface. Transparency can be affected by water color (which is changed by concentrations of large organic molecules called “humic acids”), phytoplankton abundance and particular types of species present, and turbidity caused by suspended particles from other origins. Secchi transparency readings can be affected by wind and waves, as well as by light glare off the water surface. The sample protocol calls for measurements to be made in the same fashion each time, with records of wind and sun conditions, in order to evaluate the data.

Colored water can lower the transparency readings of a lake by the reflection of certain light frequencies, while absorbing or allowing others to penetrate. In many King County lakes,

Figure 5-8. Average Secchi transparency depth from May through October, 1998 – 2002. See text for a discussion of the dotted lines.

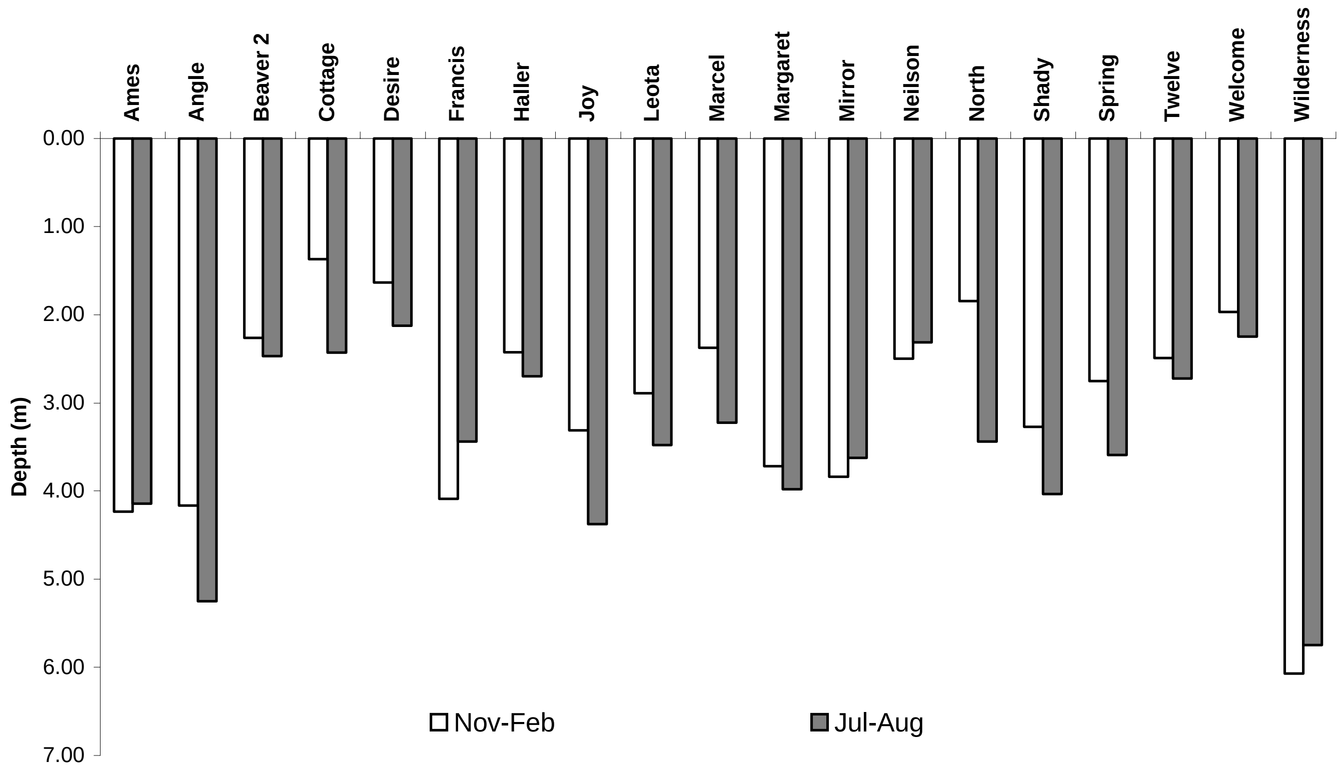


the water is naturally stained yellow or brown from the presence of large organic molecules originating from decaying matter in wetlands and soils of the watershed. Area soils tend to remain cool and wet through the year, such as those soils that are present under dense forest canopies. More plant material accumulates on the ground than can be decomposed rapidly by bacteria under the prevailing conditions. Thus, some humic acids are leached out by ground water before they are totally broken down, eventually reaching lakes. The yellow color of the water indicates that wavelengths of light in the yellow range are particularly deflected, which indicates the presence of humic acids. Therefore, the water color of a lake can give information about the rates of soil decomposition and relative saturation of soils in the watershed. Routine estimation of water color by volunteers (separate from Secchi depth) was discontinued by the Lake Stewardship Program in 2001.

A procedure that evaluates color by measuring spectral absorbance in the lower range of visible light (440 nm) was tested on one sample date in June 2002. The results suggested a fairly wide range in water color can be found among the lakes in King County (Fig. 5-7). The most highly colored lakes included Allen, Fivemile, Grass, Haller, Beaver 1, and Welcome. Lakes with the least color in the water included Meridian, Wilderness, Angle, Ravensdale and Retreat. A statistical correlation between water color and Secchi readings for that date suggested that about 72% of the variation could be explained by the relationship between the two measurements, which agrees with the supposition that color impacts Secchi readings significantly.

Transparency can also reflect changes in algal abundance, due either to changes in production or in grazing rates by zooplankton. It can also indicate major inputs of silt and detritus, such as soils dislodged by large storms or moved

Figure 5-9. Wet/dry season Secchi transparency comparisons.



into water as a result of human activities. Transparency measurements compared across years can indicate changes that may be correlated with specific events known to have occurred.

Secchi Depth 2002

Average annual Secchi depths for lakes measured by Level I volunteers over the last five years can be divided by the Trophic State Indicator (TSI), which is based on their values (Fig. 5-8). A Secchi reading of 2m equates to a TSI value of 50, which is on the threshold between mesotrophic and eutrophic productivity, while a Secchi reading of 4m equates to a TSI of 40, which marks the change from oligotrophic to mesotrophic productivity. The dotted lines in Fig. 5-8 mark these thresholds.

Annual mean Secchi values for the lakes with complete records over the past five years show a range of values over time. Lakes with clarity consistently deeper than 4m include Angle, Margaret, Meridian, and Wilderness. However, Margaret appears to be decreasing in clarity over the last five years and in 2002 was right on the threshold between oligotrophy and mesotrophy. Conversely, transparency in Pine Lake has also been below the 4m threshold, but with one exception (1999) there was a trend towards deeper average values. Most lakes were between 2 to 4m in average clarity, and there were few large fluctuations from year to year among them. Other possible trends towards decreasing clarity can be observed in Neilson, and Welcome, though these are not likely to be substantiated on the basis of just five years of data. Two lakes, Cottage and Desire, remained below the 2m threshold for all the years depicted.

In some cases, lower Secchi depths may be caused by particle inputs from storm water runoff. To evaluate this possibility, Level I Secchi depths for 2002 were divided into two time periods (Fig. 5-9) to see if the influence of storm water runoff (November-February) could be separated from influences associated with summer algal blooms (July-August). Spring and autumn data were not included because both major storm events and large phytoplankton blooms commonly occur during those seasons, thus confusing the interpretation.

During the wet months, lower transparencies were observed for 14 of the 19 lakes in the program with comprehensive annual data for Secchi depth, indicating that storm water runoff may influence water clarity in these lakes to a somewhat greater degree than summer algal populations. In addition to storm water inputs, wave action (due to strong winds) and low light levels during the winter months may be an important factor influencing lower average Secchi depth measurements.

Conclusions

Average transparency values are often similar to the previous year's values for many lakes with sufficient data for annual average calculations. Some lakes have shown an increase in clarity over the past five years, while others may have declined. Lakes Margaret, Neilson and Welcome declined enough in average annual transparency to warrant close attention, but these may not be statistically verifiable trends yet. In our geographic region, factors besides algal density influence the annual transparency measurements. Seasonal factors such as storm water inputs, lower light levels, and weather conditions can reduce water clarity during the wet winter months. Other factors, such as organic inputs, also influence water clarity. However, measuring the Secchi depth is an easy, yet powerful, way to do a quick check on water quality and should always be included in lake monitoring programs in conjunction with other measurements.

Lake Stratification and Chemistry Profiles

Seasonal changes in the water chemistry of each lake relate in part to physical differences that occur with changes in water temperature. These chemical changes are much more pronounced in thermally stratified lakes (see the water quality discussion and Fig. 1 in Chapter 1). During spring and early summer, the combination of solar heating and mixing of the near surface water in the lake causes more warming of the upper portions of the water column than in the lower depths. This results in thermal "stratification" of a lake into stable layers of water with differing temperatures and densities. Deeper lakes generally remain stratified throughout the summer, while shallow lakes exposed to wind either do not stratify thermally or else develop transient thermal stratification that breaks down often.

Effects of Stratification

Temperature patterns and thermal stratification influence fundamental processes in lakes such as changes in dissolved oxygen concentrations, nutrient release, and algal growth. Oxygen gas enters the water (dissolves) by contact with the atmosphere at the surface. Once a lake stratifies, the hypolimnion (deep water) is no longer mixing with shallow water and atmospheric gases are only in contact with upper water. This means that the dissolved oxygen in deeper water may be exhausted by the demands of bottom dwelling animals and bacteria some time after stratification has occurred. Such anoxic (no oxygen) waters can greatly stress fish like trout and salmon that require cool as well as oxygenated waters in order to survive.

In addition, chemical reactions related to anoxia can cause the sediments to release phosphorus back into the water. When this water mixes with the surface waters in autumn as cooling occurs, an algal bloom can result from the sudden influx of nutrients into surface waters from the bottom. Monitoring water chemistry differences between the epilimnion and hypolimnion during summer provides a way to assess the role that internal nutrient cycling plays in lake water chemistry.

Table 5-1. Summer profile data.

Lake name	date	Secchi (m)	depth (m)	temperature deg C	Chlor-*a* µg/L	Total P µg/L	Total N µg/L
Allen	5/20/02	0.8	1	16.0	9.79	34.8	643
			3.5		10.10	29.9	613
	9/9/02	0.8	1	17.0	15.40	23.0	774
			2.5	16.0	24.20	24.7	743
Ames	5/19/02	3.5	1	17.0	7.93	10.8	516
			7	7.5	5.87	12.1	469
	9/8/02	3.5	1	19.5	1.83	11.2	288
			7	10.0	18.60	34.6	896
Angle	5/19/02	5.0	1	15.0	3.94	10.3	335
			5.5	12.0	6.77	11.6	326
			11	8.0		12.9	501
	9/8/02	6.0	1	20.0	1.92	7.6	324
			8	19.0	1.92	7.8	308
			10	8.0		39.5	498
Beaver 1	5/21/02	1.8	1	16.0	7.20	23.6	459
			7	5.0	0.28	22.0	448
			14	5.0		49.2	614
	9/9/02	2.0	1	19.5	7.05	12.5	503
			7	5.5	1.44	14.5	513
			14	5.0		199.0	968
Beaver 2	5/19/02	2.3	1	16.0	4.63	17.6	420
			7	7.0	2.22	11.2	483
			14	6.0		15.1	508
	9/8/02	2.8	1	19.0	6.41	8.7	367
			7	8.0	1.28	12.2	462
			14	6.0		48.5	850
Bitter	5/19/02	3.7	1	15.5	2.95	10.9	257
			8	9.0	8.09	25.8	506
	9/8/02	2.0	1	19.5	4.81	14.0	326
			7.5	12.5	58.80	67.2	1700
Boren	5/19/02	3.8	1	15.5	1.69	13.9	575
			5	9.0	2.78	13.4	627
			9	5.5		14.6	773
	9/8/02	3.3	1	19.5	4.97	14.0	409
			5	6.5	6.89	13.5	302
			9	7.0		62.2	1070
Burien	5/19/02	4.0	1	16.0	4.69	11.0	350
			8	10.0	5.83	18.7	552
	9/8/02	3.0	1	18.5	4.49	15.5	442
			8	18.0	9.04	29.9	748
Cottage	5/20/02	2.0	1	15.0	11.70	21.9	975
			6.5	8.5	2.02	33.6	797
	9/9/02	3.0	1	19.0	7.05	22.7	495
			6.5	9.5	29.70	387.0	1640
Desire	5/19/02	1.3	1	16.5	18.30	29.1	538
			5	11.0	3.78	21.0	549
	9/8/02	1.5	1	19.5	123.00	31.1	585
			5	16.5	15.30	69.3	450
Fivemile	5/20/02	1.3	1	17.0	8.93	19.4	1060
			5	9.0	0.32	14.8	1010
			9	7.0		21.0	1070
	9/8/02	1.0	1	18.5	3.52	13.1	723
			5	8.5	0.48	16.0	974
			8	6.5		29.3	874
Geneva	5/19/02	6.5	1	16.0	1.14	7.4	475
			7	6.5	1.36	9.5	580
			13	5.0		101.0	856
	9/8/02	2.3	1	19.0	10.60	15.8	453
			7	9.5	3.04	32.5	375
			13	6.0		362.0	1290
Haller	5/19/02	3.5	1	14.0	3.30	15.7	417
			6	5.0	2.08	31.5	797
			9	4.0		219.0	1160
	9/8/02	2.8	1	18.5	3.68	12.4	321
			6	8.0	49.30	75.8	739
			9	4.0		582.0	3510
Joy	5/19/02	3.5	1	16.0	7.85	9.6	518
			7	7.0	6.23	11.5	652
			11.5	5.0		23.8	773
	9/8/02	4.5	1	19.0	1.92	6.8	348
			7	9.0	3.52	13.4	417
			11	5.0		16.9	1070
Kathleen	5/19/02	3.3	1	15.0	1.60	9.8	418
			5.5	10.0	0.56	18.8	564
	9/8/02	1.3	1	19.0	20.20	23.9	598
			5.5	14.5	48.70	15.2	757
Killarney	5/19/02	2.8	1	16.5	3.86	15.6	436
			3	15.0	6.99	17.5	442
	9/8/02	2.5	1	19.0	4.49	21.6	502
			3	18.5	5.13	22.1	495

Table 5-1. Summer profile data (continued).

Lake name	date	Secchi (m)	depth (m)	temperature deg C	Chlor-*a* µg/L	Total P µg/L	Total N µg/L
Langlois	5/20/02	6.3	1	15.5	4.83	8.4	295
			14	14.0	28.60	12.1	709
			28	13.0		414.0	7410
	9/9/02	8.5	1	18.0	1.20	5.6	298
			14	6.0	7.69	14.1	363
			28	4.0			
Leota	5/19/02	4.0	1	15.5	1.82	17.4	806
			3	9.0	2.44	15.5	938
			6	6.0		55.6	1060
	9/8/02	3.5	1	18.5	5.44	15.8	344
			3	16.5	30.80	21.2	423
			6	7.5		179.0	2070
Lucerne	5/20/02	3.5	1	15.0	5.01	12.8	521
			5	9.0	19.60	12.9	505
			9	6.0		11.5	638
	9/8/02	4.5	1	17.5	1.92	6.9	365
			6	15.0	3.20	< 5.0	333
			9	6.5		45.3	1020
Marcel	5/19/02	2.5	1	15.5	7.41	13.9	1010
			4	11.5	64.20	42.6	1120
	9/8/02	3.0	1	18.5	4.97	12.0	482
			3	18.2	1.76	10.9	418
Margaret	5/19/02	4.0	1	14.5	1.22	8.7	440
			6	7.5	5.33	10.9	419
			11	6.0		9.5	475
	9/8/02	3.3	1	18.0	2.40	7.0	241
			6	11.0	11.20	11.2	294
			11	7.0		6.9	572
McDonald	5/19/02	0.3	1	16.0	4.85	16.7	431
			7	9.0	10.80	26.1	570
			13	5.0		21.7	647
	9/8/02	4.5	1	19.0	4.49	15.2	400
			7	18.0	4.65	14.0	378
			13	9.0		37.6	378
Meridian	5/19/02	5.0	1	16.0	3.02	7.5	274
			13	6.0	2.90	7.2	384
			26	6.0		15.4	552
	9/8/02	5.0	1	20.0	2.08	7.5	337
			13	17.0	1.60	7.8	500
			23	6.0		115.0	625
Mirror	5/20/02	6.0	1	17.0	1.74	8.0	265
			5.5		7.89	15.0	298
	9/9/02	3.5	1	20.0	4.65	7.4	386
			5.5	19.0	8.17	12.3	492

Lake name	date	Secchi (m)	depth (m)	temperature deg C	Chlor-*a* µg/L	Total P µg/L	Total N µg/L
Morton	5/19/02	3.8	1	17.0	2.86	7.2	395
			4	12.0	6.29	8.2	410
	9/8/02	3.3	1	20.0	3.52	7.1	404
			4	19.0	3.04	6.6	400
Neilson	5/19/02	3.0	1	16.0	4.55	15.5	542
			4	9.0	9.27	15.0	629
			8	5.5		21.2	688
	9/8/02	2.8	1	18.0	6.25	11.2	458
			4	13.0	7.37	14.5	447
			8	6.0		55.4	1060
North	5/19/02	2.3	1	16.0	2.59	14.9	532
			9	9.0	7.19	32.3	711
	9/8/02	2.3	1	20.0	5.93	8.6	467
			9	9.5	98.00	25.3	1130
Paradise	5/20/02	2.0	1	14.0	24.10	25.1	621
			4	6.5	2.58	18.9	751
			7.5	5.0		88.4	847
	9/8/02	2.0	1	15.0	51.90	27.0	416
			4	12.0	37.20	37.0	501
			7.5	6.0		550.0	2570
Pine	5/19/02	6.0	1	15.5	1.94	7.8	352
			6	11.0	4.01	11.5	415
			10	8.0		14.9	486
	9/8/02	4.0	1	19.5	5.13	9.3	375
			6	19.0	6.19	9.2	357
			10	9.0		54.8	747
Pipe	5/20/02	4.3	1	15.5	4.79	10.2	419
			10	6.0	2.48	6.8	464
			19	5.0		7.5	523
	9/10/02	4.3	1	21.0	2.24	6.2	358
			8	17.0	2.24	5.3	337
Ravensdale	5/19/02	5.0	1	7.0	1.36	7.1	682
			4		6.55	9.4	727
	9/8/02	4.8	1	14.0	7.53	20.2	742
			4	9.0	2.40	11.1	619
Retreat	5/19/02	8.3	1	14.5	2.20	5.7	666
			7	11.5	4.87	6.7	646
			12	9.0		65.8	317
	9/8/02	3.8	1	20.5	6.09	8.0	470
			7	20.0	5.61	7.3	351
			12.5	13.0		13.6	1470

Table 5-1. Summary profile data (continued).

Lake name	date	Secchi (m)	depth (m)	temperature deg C	Chlor-a µg/L	Total P µg/L	Total N µg/L
Sawyer	5/19/02	3.0	1	15.0	9.41	9.9	499
			8	12.5	3.22	8.7	635
			16.5	5.5		13.4	675
	9/9/02	5.5	1	19.0	2.88	11.2	209
			8	17.0	9.13	14.7	500
			16.5	16.0		95.3	847
Shadow	5/19/02	2.3	1	16.0	3.66	52.1	893
			4.5	8.0	1.68	14.9	912
			9	5.0		16.6	903
	9/8/02	3.3	1	19.0	3.68	8.8	431
			5	10.0	11.20	18.3	708
			9	6.0		18.1	837
Shady	5/19/02	4.3	1	16.7	7.10	7.3	346
			6	7.0	33.50	14.7	608
			12	5.0		16.5	783
	9/8/02	5.2	1	20.0	1.80	< 5.0	330
			6	13.0	9.13	9.3	341
			12	5.4		9.0	1510
Spring	5/19/02	1.8	1	17.5	3.36	9.9	605
			4	9.0	1.28	10.4	661
			8	7.0		15.7	632
	9/8/02	4.0	1	20.0	3.89	18.5	452
			4	18.0	5.93	10.5	332
			8	8.5		62.4	720
Star	5/20/02	5.0	1	18.0	2.82	9.2	328
			7	10.0	15.30	12.1	432
			14	7.0		58.1	854
	9/9/02	2.8	1	21.5	5.29	9.4	316
			7	17.5	3.04	7.7	249
			14	8.5		169.0	1930
Steel	5/20/02	5.5	1	17.0	2.14	9.6	239
			6	14.0	38.90	16.4	267
	9/9/02	3.8	1	20.0	6.01	9.9	370
			6	19.5	4.17	14.1	375
Trout	5/20/02	1.8	1	16.0	7.51	19.3	1050
			4	7.5	1.02	24.1	1100
			7	6.5		62.2	1420
	9/9/02	3.5	1		6.73	19.2	724
			4	7.0	4.91	29.2	611
			7	19.0		263.0	2040
Twelve	5/20/02	4.8	1	15.0	1.07	8.2	403
			7	7.0	0.86	10.8	435
	9/9/02	2.8	1	17.0	13.50	9.6	425
			6.5	15.0	37.30	30.2	554
Walsh	5/19/02	3.0	1	7.0	3.34	8.4	434
			5	7.0	11.60	13.2	491
			10	6.0		12.5	533
	9/8/02	4.0	1	18.0	2.40	8.8	234
			5	15.0	3.84	15.0	277
			10	7.0		8.8	464
Welcome	5/19/02	2.4	1	15.7	4.94	13.7	553
			3.5	9.0	1.94	13.0	579
	9/8/02	3.0	1	18.8	2.40	11.5	446
			3.5	17.5	4.17	12.9	472
Wilderness	5/19/02	5.0	1	15.0	3.69	16.3	720
			6	9.0	3.66	19.6	658
			8.5	7.5		66.9	555
	9/8/02	4.3	1	19.0	9.77	20.2	322
			6	18.5	18.90	26.6	372
			8	12.0		291.0	1200

2002 Profiles

Samples were taken at two or three depths, depending on the maximum depth of each lake, for temperature, chlorophyll *a*, total phosphorus, and total nitrogen by Level II volunteer monitors (Table 5-1). The precise sampling depths were based on the actual depth measured at the sampling site, with samples taken 1m from the surface, the middle of the water column, and 1m above the measured bottom. These samples were collected in late May and again in early September in order to characterize changes in the water column over the summer during the most probable period of stratification. Lakes with stable thermal stratification usually show the most dramatic differences in water chemistry between the top and bottom samples in late summer.

In the Pacific Northwest, most lakes that stratify have already done so by May and retain the stratification until some time in October. Water temperatures will reflect this if comparisons are made between the top and bottom values. Shallow lakes such as Allen, Burien, Killarney, Marcel, Mirror, Steel and Welcome show very little difference between the temperatures at the top and bottom, or a difference on only one of the two dates, suggesting that stratification, if occurring, is probably of short duration.

For many lakes, total phosphorus levels were typically larger in bottom water samples by August compared to 1m and mid-depth concentrations, suggesting that significant release of phosphorus from the sediments was occurring over the summer months. The measurement of the total amount of phosphorus is not a direct measure of the phosphorus that is available for algal uptake, since the phosphorus contained in particles both organic and inorganic will be included in the test. However, major difference in bottom sample phosphorus concentrations between May and September do suggest that some release from the sediments is occurring.

There are several possible sources of errors in phosphorus measurements of the bottom samples. If any bottom sediments were disturbed during sampling, they might be incorporated in the sample, and measured levels could be very high, but would not reflect what was actually present and available for phytoplankton growth. Volunteers were instructed to discard the water if it appeared to include any bottom sediments and to collect another sample. Another potential source for error in shallow lakes might be incorporation of material from rooted aquatic plants in the deep sample. By August, several of the shallower lakes can have aquatic plants growing up from the bottom all across the lake, including at the sample site. Material sinking from the shallow water can get caught in these plants and then disturbed when the sampler is dropped through the water, thus incorporating extra particulate matter into the sample water. This would then give a high reading that would not be at all related to chemical release of sedimentary phosphorus.

Very high concentrations of total phosphorus (> 200 µg/L) on one or both profile dates were found in the bottom samples of lakes Cottage, Geneva, Haller, Langlois, Paradise, Trout, and Wilderness. For these lakes, phosphorus release from the sediments likely increased the potential for algal growth in the future, and could be increasing the values of the Trophic State Indicators as well. For most of the other lakes, the process of internal phosphorus recycling due to anoxia in the hypolimnion probably did not contribute significantly to the phosphorus budget in 2002.

Total nitrogen showed very similar patterns, but not precisely the same relationships from lake to lake. Nitrogen chemistry is more complex than phosphorus, and it is generally of less concern for management strategies in the Pacific Northwest because it is not often the nutrient in least supply for algae in the lakes of King County. However, it does affect the nitrogen to phosphorus ratio present in each lake, which gives some algae an advantage over other species. Nitrogen is often about an order of magnitude higher in concentration than phosphorus in freshwater. Lakes which had very high concentrations of total nitrogen (>1500 µg/L) on one or more dates included Bitter, Cottage, Haller, Leota, Paradise, Shady, Star, and Trout.

Chlorophyll *a* was measured at the same depths as phytoplankton samples were taken (see Chapter 4). There were some lakes where chlorophyll was much greater at the surface than at mid-depth on one or both dates, including Beaver 1, Cottage, Desire, and Paradise. More lakes showed the reverse pattern of greater chlorophyll *a* in deep water than at 1m, and for some of them the difference was quite large. Lakes with this pattern on one or both dates included Ames, Bitter, Cottage, Haller, Kathleen, Langlois, Leota, Lucerne, Marcel, North, Shady, Star, Steel, Twelve, and Wilderness.

Conclusions

Many lakes in King County exhibit some degree of thermal stratification by the beginning of summer. Some of the shallow lakes remain unstratified or stratify only for brief periods due to the diffusion of heat through the water column and mixing actions by wind. In most lakes with stable thermoclines, nutrient concentrations were higher in the bottom samples during one or both profile sampling dates. Many lakes had more chlorophyll in the mid-depth sample than in the 1m sample, and this can be compared to the phytoplankton counts.

Trophic State Index

The productivity of lakes can be classified using numbers that predict biological activity by calculating the Trophic State Index (TSI) based on conditions in the lake. TSI values provide a standard measure to rate lakes on a scale of 0 to 100. Each major division (10, 20, 30, and so on) correlates the doubling of algal biovolume to various measurable parameters by linear regression and re-scaling (Carlson, 1977). The indices are based on the summer mean values (May through October) of three commonly measured lake parameters: Secchi depth, total phosphorus, and chlorophyll *a*.

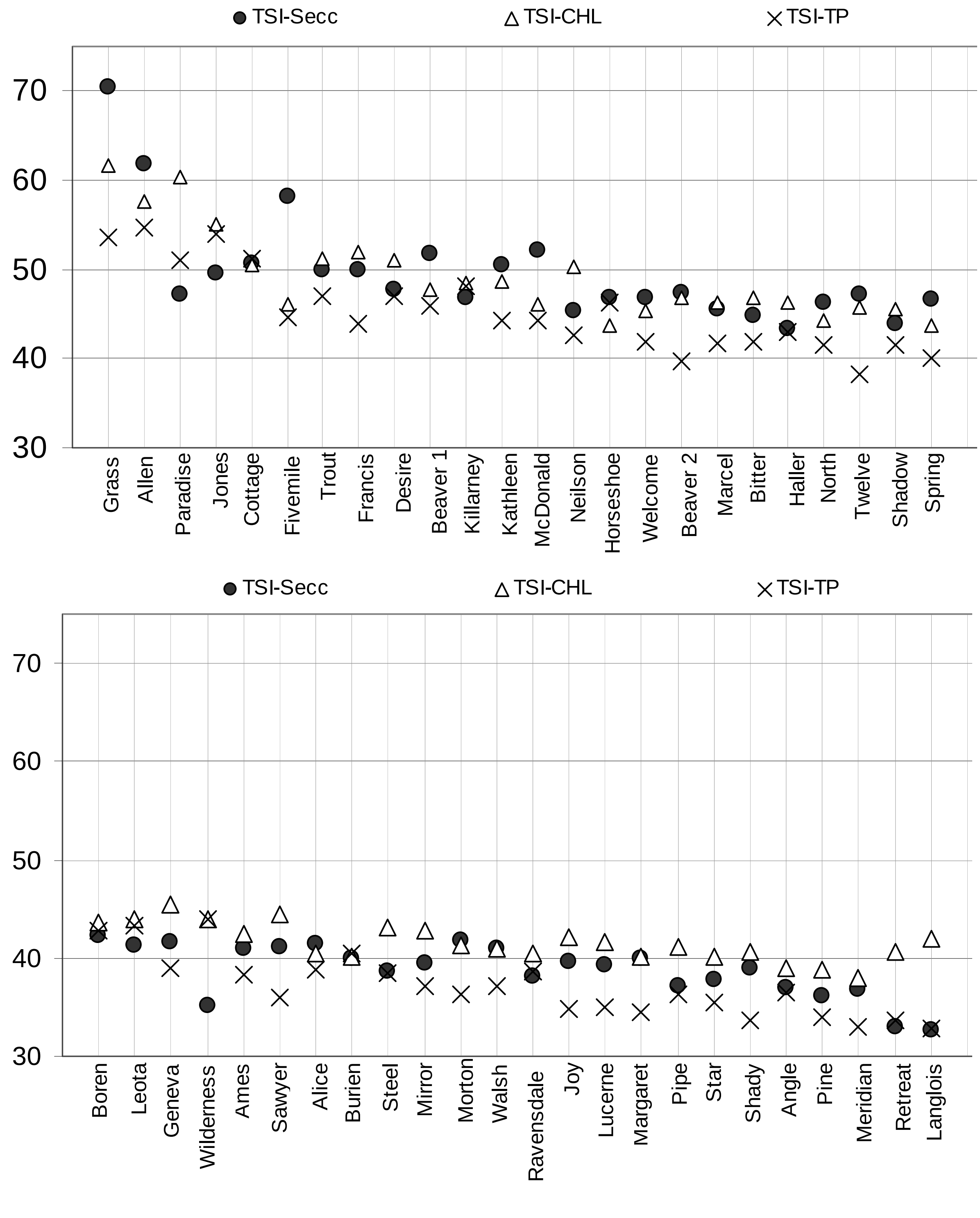
The relationships are not always straightforward. Carlson points out that lakes that are highly colored due to dissolved organic matter may produce erroneously high TSI ratings for Secchi transparency. The shape and size of phytoplankton species can also influence the Secchi and the chlorophyll ratings, since small, diffuse algae cloud the water more than large, dense algal colonies and species of algae vary in the amount of chlorophyll they contain. Additionally, it is important to note that the total phosphorus measure is most reliable for lakes that are strictly phosphorus limited in algal nutrition, and the relationship often falls apart when nitrogen is the limiting nutrient. Although no lakes in King County have been identified as solely governed by nitrogen limitation, there are several lakes in which nitrogen appears to be limiting at times through the season or in which phosphorus and nitrogen limitations are occasionally combined.

2002 TSI Ratings

TSI values were calculated for the three parameters measured on each sampling date for the 48 lakes monitored by Level II volunteers (Figure 5-10), and the average for each was produced for the season. The lakes were arranged by the average of all three TSI values in descending order to show the range of values found for monitored lakes in the county. TSI values over the past nine years for each lake are included in the individual lake descriptions (Chapter 3).

Carlson (1977) points out that if all the assumptions are correct, the TSI values produced from the three different parameters should be very close to each other. Many King County lakes follow this prediction, but several have values that are not very close, suggesting that some different conditions are important at those lakes. When lakes have two close TSI values and one very different one, the outlying value could be excluded from consideration if a reasonable hypothesis is put forward to explain the differing value. For example, there are four King County lakes in 2002 whose trophic assignment could be reassessed, based on the difference between the TSI-Secchi and the other values: Grass, Fivemile, McDonald, and Wilderness. Fivemile is easy to evaluate because the TSI-TP and TSI-chlor are close together, while the TSI-Secchi is much higher, similar to the stituation 2001. The color of the water in the lake is yellow (see Fig. 5-7), which is likely to raise the TSI value higher than its productivity might merit. Fivemile can then be assessed on the basis of the other two indicators, and productivity appears to be in the mid-mesotrophic range rather than eutrophic. While the three trophic indicators for Grass Lake are far apart, they are all in the eutrophic range, so eliminating one of them does not change its classification.

Figure 5-10. Average trophic state indicators (TSI) for Level II Lakes, 2002.



Values less than 40 denote oligotrophic lakes
Values between 40 and 50 denote mesotrophic lakes
Values equal or greater than 50 denote eutrophic lakes

In contrast, Lake Wilderness has two TSI values that range in the middle of mesotrophic, but the TSI-Secchi places well below the oligotrophic threshold. If the phytoplankton data are compared to the Secchi data, it is apparent that the bluegreens *Aphanizomenon* and *Gloeotrichia* dominated the phytoplankton during the time of higher transparency in the spring and fall. *Aphanizomenon* makes dense, long and narrow colonies resembling blades of grass, while *Gloeotrichia* makes dense balls of filaments. Neither shape interferes with clarity to the same extent as more diffuse colonies of algae or myriads of individual cells. Thus, the Secchi readings might not reflect the higher productivity during those times when the bluegreens were abundant, and productivity would likely be better represented by the chlorophyll *a* and total phosphorus TSI values. This puts Lake Wilderness in the middle range of mesotrophy.

Oligotrophic lakes with TSI values less than 40 are considered to have low biological activity, with high clarity and low concentrations of chlorophyll *a* and total phosphorus. Four lakes met this criterion for all three calculations of TSI: Angle, Pine, Meridian, and Star. Eight other lakes had two out of three TSI values below 40: Langlois, Retreat, Shady, Pipe, Margaret, Lucerne, Joy, and Ravensdale. Lakes Ames, Burien and Alice are borderline between oligotrophy and mesotrophy.

Mesotrophic lakes have TSI ratings between 40 and 50. They are considered to be transitional between being relatively nonproductive and very productive biologically. In 2002, there were five lakes just above the threshold between mesotrophy and oligotrophy, including Walsh, Morton, Mirror, Steel, and Sawyer. Other lakes in the lower range of mesotrophy included Geneva, Leota, Boren, Spring, and Shadow. Lake Twelve had two TSI values above the mid-range of mesotrophy, but a low TSI-TP.

The middle to high range mesotrophic lakes, with all three indicators in the 40-50 range, included North, Haller, Bitter, Marcel, Welcome, Horseshoe, and Killarney. Beaver 2 had two TSI values in high mesotrophy, but the TSI-TP was below 40. McDonald also had two TSI values in midrange mesotrophy, but the TSI-Secchi was higher than 50, putting it at the threshold. Other lakes with two indicators between 40 to 50 and one above 50 included Neilson, Kathleen, Beaver 1, Desire, Trout, and Francis. Fivemile Lake is a special case, as discussed previously, and should be included in the mid-mesotrophic range.

Lakes that have TSI values greater than 50 are considered eutrophic, characterized by high biological productivity. Only three lakes were rated eutrophic in 2002 by all three TSI values: Allen, Cottage and Grass. Lakes with two out of three above included Jones and Paradise. Fivemile Lake is a special case, as discussed previously.

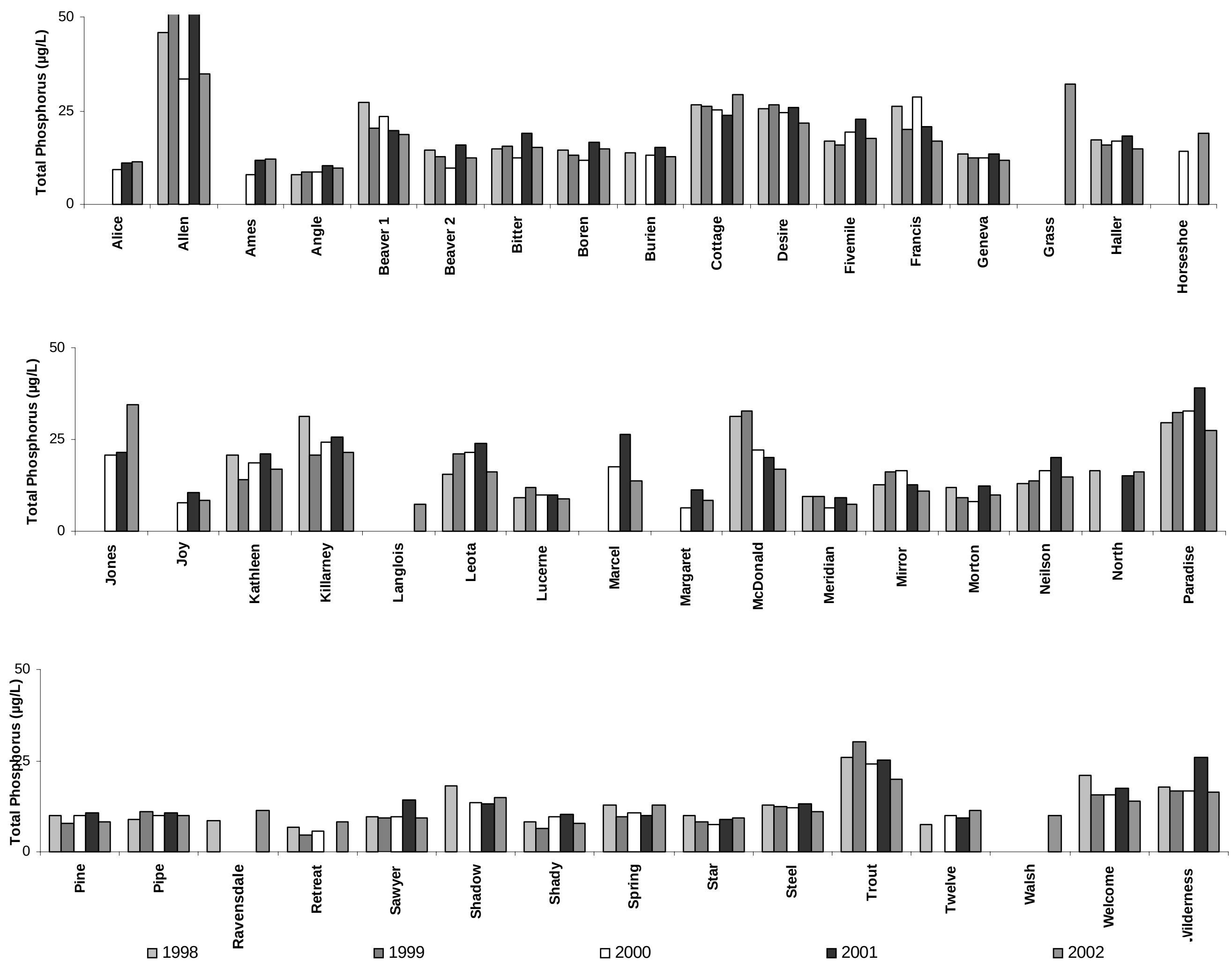
Conclusions

The TSI rating can be useful in the comparison of the water quality of particular lakes over time. It may also be used to assess potential sensitivity of each lake to additional nutrient inputs. Changes in land use within a watershed and other factors can add nutrients to the system. Many lakes in the Lake Stewardship sampling program maintain relatively constant TSI ratings from year to year (see Chapter 3 for specific lakes), partially because the calculations are not sensitive to minor variations in the parameters used to calculate them. However, when directional changes are observed, these can be used as starting points for more detailed studies to determine if and how management activities might be implemented.

Total Phosphorus

Many lakes have similar mean phosphorus levels from year to year, with some variation that is to be expected. Thirty of the 43 lakes with three or more years of Level II data

Figure 5-11. Average total phosphorus concentrations, May - October, 1998-2002.



yielded similar or slightly variable total phosphorus over the past five years (Figure 5-11). However, total phosphorus has been dropping steadily over the last five years in several lakes, notably Beaver 1, Desire, and McDonald. Cottage dropped over four years in a row, but increased in 2002. Other lakes may also be declining in total phosphorus, but the record is clouded by one or more higher years, including Francis, Trout, and Welcome.

Grass, Horseshoe, Langlois, and Walsh lakes reported Level II data for the first or second time, while North and Ravensdale reported data after a hiatus. These will need several more years of data collection before patterns begin to emerge.

Several lakes showed a steady increase of phosphorus over the last five years of data collection, including Alice, Ames, and Twelve. Neilson increased four years in a row, but decreased in 2002. Total phosphorus in Allen Lake has varied widely over the past five years, but is always high. No lakes have increased in total phosphorus over a long enough period of time for trends to be considered statistically significant. However, the increases do point to lakes that should have careful attention paid to them over the next few years.

Nitrogen: Phosphorus Ratios

Many water quality problems in lakes can be related to high concentrations of nutrients that stimulate the growth of algae and aquatic plants. In temperate freshwater systems, the nutrient that limits algae growth is most often phosphorus, although phytoplankton can be occasionally limited by nitrogen concentrations or even by silica or iron. Before trying to manage a water quality problem, it is important to know which nutrient is limiting plant growth most frequently.

To make a quick nutrient assessment, nitrogen to phosphorus ratios (N:P) are calculated for individual lakes. Generally, nitrogen to phosphorus ratios of 17:1 or greater suggest that phosphorus limits algal growth (Carroll and Pelletier 1991). This ratio varies throughout the growing season. Some lakes are primarily phosphorus limited, but occasionally may be nitrogen limited. Others are solely governed by one nutrient which is in the shortest supply through the season. Lower nitrogen to phosphorus ratios can favor bluegreens over other algal species, because some bluegreens are able to use nitrogen from the air, unlike other algae. A ratio of 20:1 or below is often indicative of potentially advantageous conditions for bluegreen growth.

A biological wrinkle in using N:P ratios to assess the potential for algal growth is that some algae can take up phosphorus (so-called “luxury uptake”) and store it for use later in the season when phosphorus concentrations have become very low in the epilimnion. Thus, the population growth rates of such algae may be reflecting earlier conditions of phosphorus availability rather than the period during which they are being measured.

2002 Ratios

No Level II lakes had average N:P ratios less than 20 for the period of May-October 2002 (Fig. 5-12), although values below 20 have been common for certain lakes over the past nine years. Many of the lakes have had lower average ratios than they have now, suggesting that algae in these lakes could have experienced nitrogen limitation during portions of the growing seasons in past years. Upward trends through time in N:P ratios can be seen for 21 of the 48 lakes, which could be signaling changes away from domination by bluegreen populations in the future. The ratio in other lakes has changed greatly from year to year or has shown no particular trend or directionality.

Lakes that ranked as oligotrophic by their TSI indicators generally also had higher N:P ratios, while eutrophic lakes had lower N:P ratios. One lake which was contrary in this regard is Fivemile, which had generally high N:P ratios although ranked as midrange mesotrophic, with a eutrophic TSI-Secchi likely due to water color.

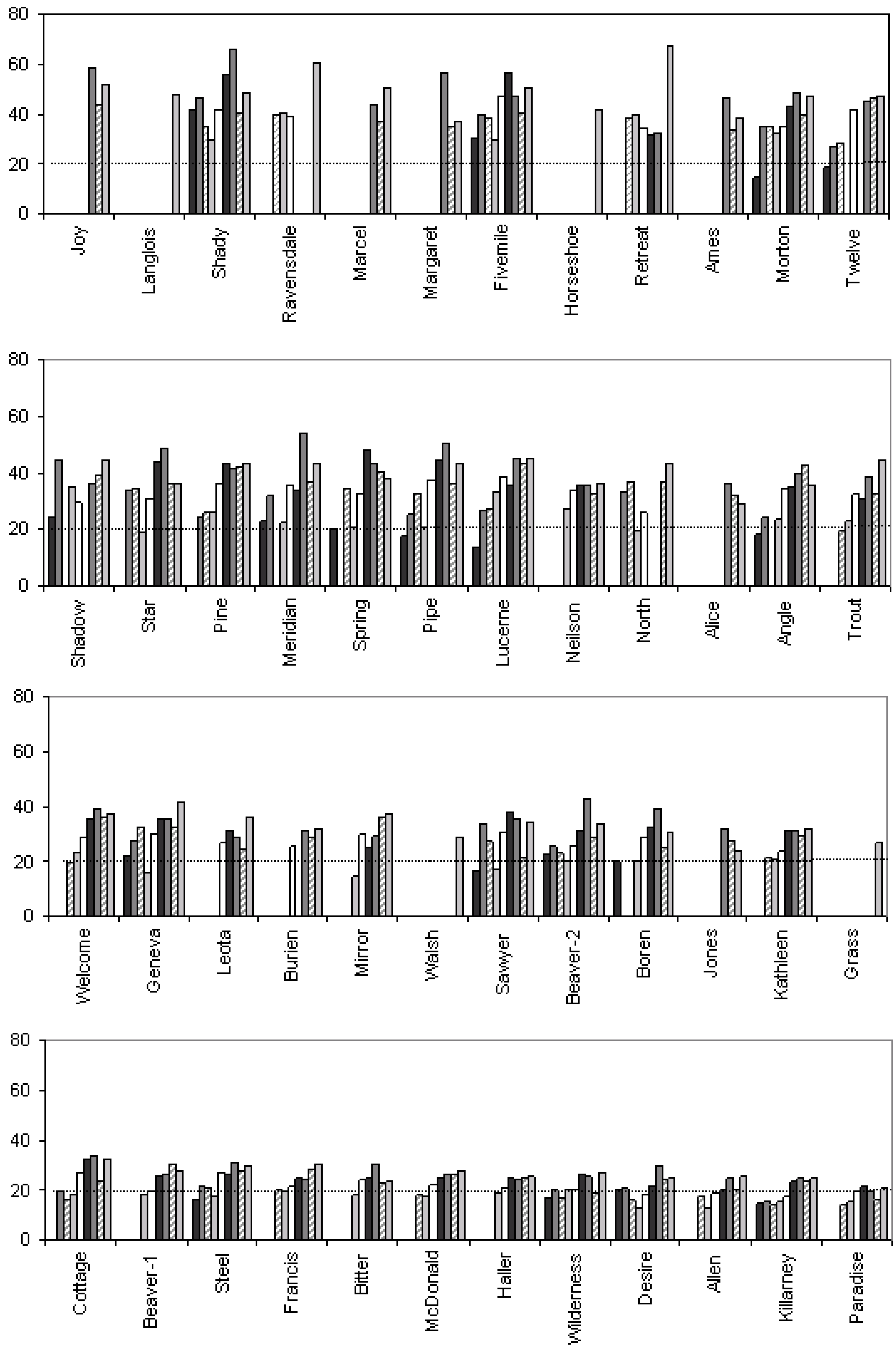
Conclusions

In 2002, lakes with Level II data ranged from 21 to 52 in average N:P ratio, with the oligotrophic lakes having generally the highest N:P values and the eutrophic lakes having the lowest. Mesotrophic lakes had the widest range. While there are quite a few lakes with ratios that have increased over time, none have steadily decreased.

Chlorophyll a

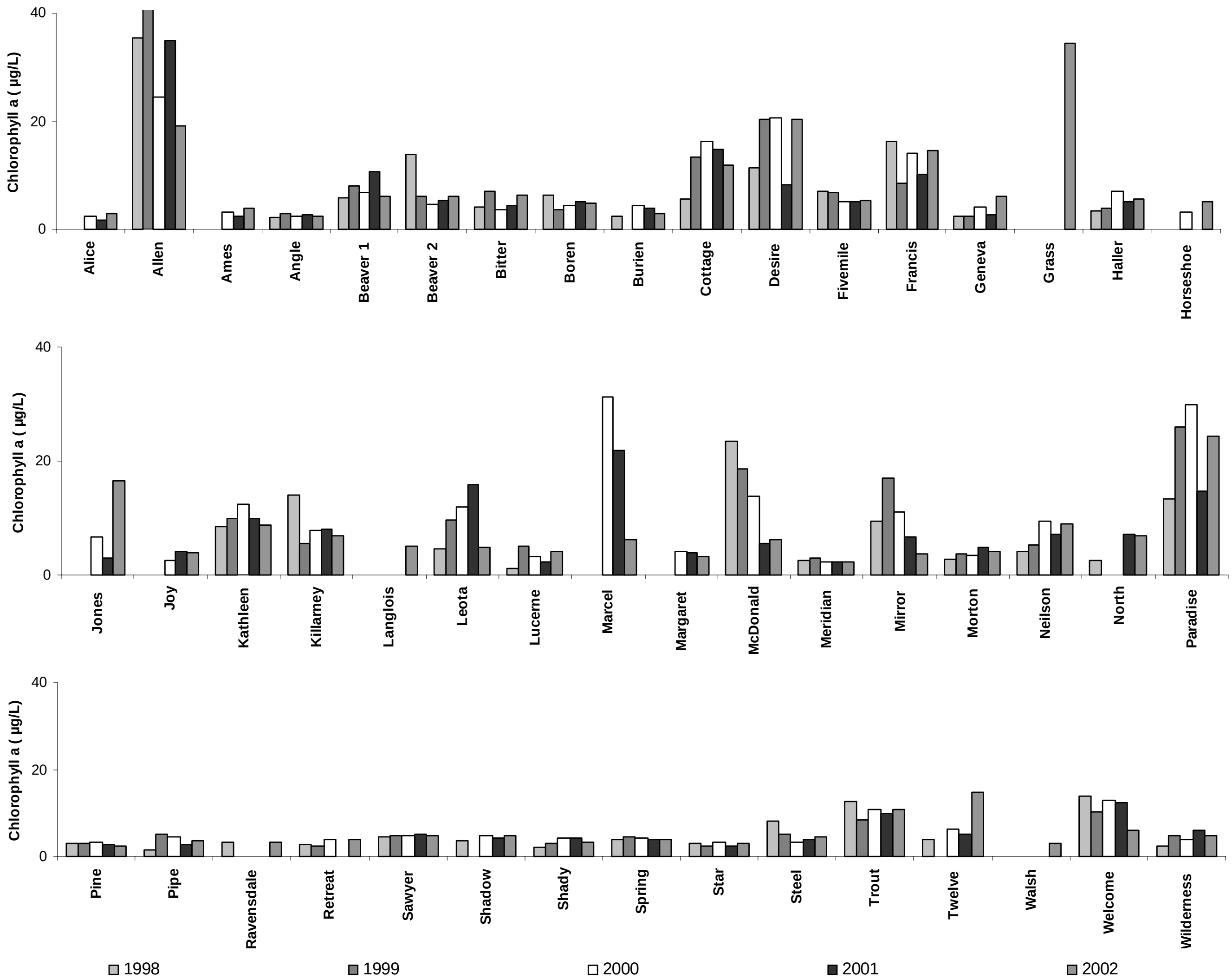
Variability is often much greater from year to year in chlorophyll *a* concentrations than it is for total phosphorus or the N:P ratio. This is not surprising, since the phytoplankton populations in a lake can be concentrated by wind and water movements and so may not be evenly distributed at the time of sampling. In addition, algal species present in a lake can change from year to year, and algae differ in the amount of chlorophyll per cell by species. The amount of chlorophyll *a* per cell can also vary with the health and age of the population as well. For example, large blooms of cyanobacteria (bluegreens) may yield less chlorophyll than equivalent volumes of chlorophytes (green algae)

Figure 5-12. Average Nitrogen to Phosphorus ratios, May – October, 1994-2002.



Values below 20 may encourage bluegreen algae.

Figure 5-13. Average chlorophyll-a concentrations, May – October, 1998-2002.



because many bluegreens have accessory pigments in addition to the chlorophyll that are used to capture light for photosynthesis. Lack of wind can cause bluegreens to float up to the surface, concentrating them at the top of the water column, while other species, such as chlorophytes and diatoms, may sink down towards the thermocline, out of the surface water.

Even with all the variables that come into play on each sampling date, the annual May-October averages of chlorophyll (Fig. 5-13) demonstrate that most of the lakes in the program have generally similar average concentrations from year to year or else vary within a certain range. This is particularly true of lakes with lower average concentrations, of which there are many: Alice, Ames, Angle, Bitter, Boren, Burien, Fivemile, Geneva, Haller, Horseshoe, Joy, Langlois, Lucerne, Margaret, Meridian, Morton, Pine, Pipe, Ravensdale, Retreat, Sawyer, Shadow, Shady, Spring, Star, Twelve, Walsh, and Wilderness.

Average chlorophyll concentrations in Allen Lake vary a great deal from year to year, but are always much higher than in the other lakes participating in the program, with the exception of Grass, a lake new to the program this year.

Several other lakes which are also consistently higher than others include Cottage, Desire, Francis, Kathleen, Killarney, Leota, Paradise, Trout, and Welcome. Marcel has decreased sharply over the three years of monitoring. McDonald decreased steadily from 1998 to 2001, but remained steady in 2002. Mirror had a peak in 1999 and has decreased since then. Welcome may also be decreasing, with a sharp decline in 2002. Leota appeared to be increasing over time, but dropped in 2002 back to 1998.

A few lakes have one or two significantly higher years, such as Beaver 1 and Beaver 2 (oddly enough, these are in different years), or Lake Killarney in 1998. Alternatively, there may be one or two lower years, such as 2001 for Lake Desire. Such values can be anomalous and not repeated in the future, or could also be indications of regular, but ephemeral blooms that coincided with a sampling date in a particular year, but was missed in others because of the two-week gap between sample collections.

Conclusion

Average concentrations of chlorophyll *a* may vary a great deal from year to year, particularly in lakes with large amounts of algae. Concentration of algae by wind and water movements can lead to samples that are not representative of the lake as a whole, being either too high or too low. However, chlorophyll concentrations are rarely high at lakes with low overall productivity and the yearly averages generally appear to be within a constant range. Chlorophyll tends to vary more at lakes with high phytoplankton abundances, such as at Allen. As a measure of productivity, chlorophyll may be subject to more variation than either Secchi or TP.

Program Summary and Outlook

The 2002 monitoring program, which ran from October 2001 through September 2002, represented the ongoing effort by King County to expand the information available on the smaller lakes within its boundaries. The program continued to be refined to make the most of limited resources and changing jurisdictions within King County, while the program's staff also remained committed to making the most of the volunteer monitors' time and effort.

Changes may continue to occur for both the methods of collection and reporting as adjustments are made in response to volunteer requests and staff observations. Some parameters may be discontinued, while others may be added to the program if the information gained is considered to be important in assessing the condition of the lakes.

The Lake Stewardship Program's Web site, **http://dnr.metrokc.gov/wlr/waterres/smlakes**, continues to feature lake management information, as well as electronic copies of as many of our publications as possible. In addition, the site highlights the efforts of our volunteer monitors and provides information to people interested in joining the data collection program.

The Lake Stewardship Program staff provides our volunteers with technical assistance and answers to questions relating to limnological processes or conditions found at specific lakes. Please give us a call with concerns and feedback. We always enjoy hearing from you.

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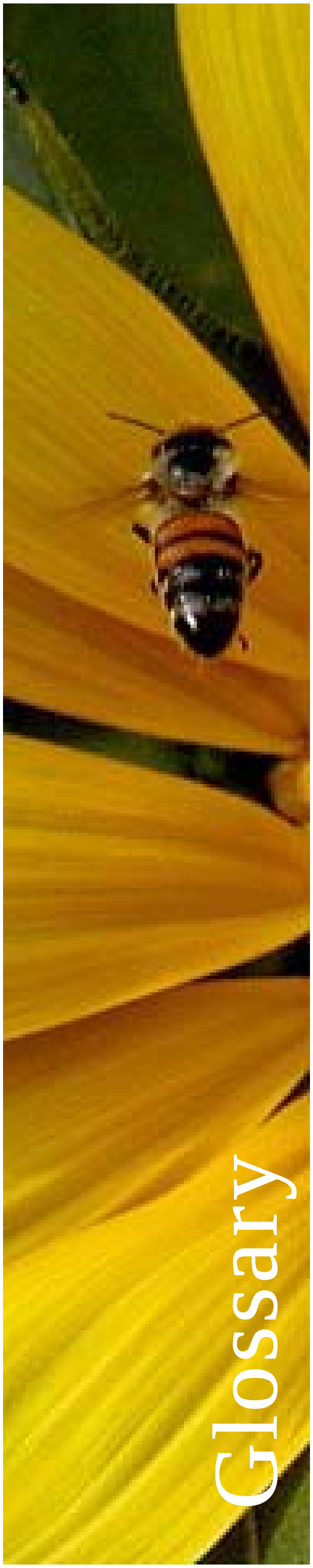
Conversion Units

The units used throughout this report are based on the International Systems of Units (the SI or metric system) which is standard for most scientific work. The exception to the use of these units is found in Table 1 where the summary of physical characteristics of the monitored lakes remains in English Units.

SI or Metric	English	
1 kilometer (km)	0.62	miles
1 meter (m)	39	inches
1 centimeter (cm)	0.39	inches
1 millimeter (mm)	0.039	inches
1 micrometer (µm)	0.000039	inches
1 hectare (ha)	2.47	acres
1 square meter (m^2)	10.76	square feet
1 cubic meter (m^3)	1.3	cubic yards
1 cubic centimeter (cm^3)	0.061	cubic inches
1 liter (L)	1.04	quarts
1 milliliter (mL)	0.20	teaspoons
1 kilogram (kg)	35.3	ounces
1 gram (g)	0.0353	ounces
1 milligram (mg)	0.0000353	ounces
1 milligram/liter (mg/L)	0.0083	pounds/gallon
1 microgram/liter (µg/l)	0.0000083	pounds/gallon
1 degree Celsius (°C)	(°C x 9/5) + 32	degree Fahrenheit (°F)



Aerobic: Living in the presence of oxygen. Most organisms are aerobic and must have oxygen available in order to survive.

Algae: Single celled nonvascular plants occurring singly or in groups (colonies). They contain chlorophyll *a*, used to produce their own food by means of photosynthesis. Algae form the base of the food chain in aquatic environments.

Algal Bloom: Heavy growth of algae in and on a body of water, often a result of high nutrient concentrations.

Alkalinity: The acid neutralizing capacity of a solution, usually related to the amount of carbonates present; buffering capacity.

Anaerobic: Living in the absence of oxygen. Some bacteria can survive and grow without oxygen present.

Anoxic: No oxygen present in the system; see anaerobic.

Average: (see “Mean”) The sum of a group of numbers divided by the total number of values in the group.

Bathymetric Map: A map showing the bottom contours and depth of a lake.

Benthic: Bottom area of the lake which hosts the community of organisms (benthos) that live in or on the sediment.

Biovolume: Space occupied by organic matter.

Catchment Basin: See “Watershed.”

Chlorophyll *a*: A green pigment in plants which is used to capture light energy and convert it, along with water and carbon dioxide, into food or organic material.

Concentration: The amount of one substance in a unit amount of another substance, such as a specific weight of a chemical in a given volume of water.

Conductivity: The measure of water's capacity to convey an electric current. Increasing the numbers of dissolved ions also increases the conductivity.

Dissolved Oxygen: The oxygen gas that is dissolved in water as O_2.

Ecosystem: Any complex of living organisms with all other factors that affect them and are affected by them.

Epilimnion: The warmer, less dense, upper layer of a lake lying above cooler water (metalimnion and hypolimnion) in some seasons of the year.

Eutrophic: Waters containing algae making large populations and biovolumes, generally related to nutrient supply.

Eutrophication: The physical, chemical, and biological changes associated with enrichment of a body of freshwater due to increases in nutrients and sedimentation.

Fall Turnover: The mixing of thermally stratified waters that commonly occurs during early autumn. The sequence of events leading to a fall turnover includes: cooling of surface waters leading to a density change in surface water that produces convection currents from top to bottom, and circulation of the total water volume by wind action. Turnover generally results in uniformity of the physical and chemical properties of the water.

Humic Substances: Organic substances incompletely broken down by decomposers such as bacteria. Humic acids are large molecular organic acids that are present in water, often giving the water a yellow or brown color.

Hypolimnion: The colder, dense, deep water layer in a thermally stratified lake, lying below the metalimnion and removed from surface influences.

Level I sampling: An annual volunteer monitoring program managed by the King County Lake Stewardship Program. The program involves daily measurements of precipitation and lake level, as well as weekly measurements of surface water temperature and water clarity, and observations on aquatic plant growth, lake use, and numbers of geese throughout the year.

Level II sampling: A seasonal volunteer monitoring program managed by the King County Lake Stewardship Program. The program involves biweekly measurements of surface water temperature and water clarity, collecting water samples for laboratory analysis, and observations on aquatic plant growth, lake use and numbers of geese from late April through October.

Limiting Nutrient: Essential nutrient that is available in the smallest amount in the environment, relative to the needs of the organisms.

Limnology: The study of lakes and inland waters as ecosystems.

Littoral: The shallow region in a body of water which can be inhabited by rooted aquatic plants. This is somewhat dependent on the ability of light to penetrate the water. Specific animal groups also inhabit this zone.

Loading: The total amount of material (sediment or nutrients) entering a water body via streams, overland flow, precipitation, direct discharge, or other means over time (usually considered annually). Recycling of nutrients among sediment, organisms and water is sometimes referred to as "internal loading."

Mean: (see "Average") The sum of a group of numbers divided by the total number of values in the group.

Median: The datum in a set of numbers that represents the exact center of the group: half of the numbers are smaller and the other half are larger.

Metalimnion: The layer of water in a lake between the epilimnion and hypolimnion in which the temperature and thus density change rapidly over a short distance.

Monomictic: A water pattern of lakes in which thermal mixing and stable stratification alternate once per year.

Nitrogen: One of the elements essential for the growth of organisms. Nitrogen is most abundant on the earth in the form of N_2, comprising 80% of the atmosphere, but is usually taken up by plants in the forms NO_3, NO_2 and NH_3.

Nonpoint Source Pollution: Pollution from a diverse set of sources difficult to pinpoint as separate entities and thus to control or manage. Examples of "nonpoint sources" include area-wide erosion (as opposed to landslides or mass wasting), failure of septic systems, some farming practices or forestry practices, and residential/urban land uses (such as fertilizing or landscaping).

Noxious weeds: A legal definition of by the State of Washington that lists specific non-native, invasive plants known to destroy habitat for other plants or animals, or documented as having caused serious agricultural problems. A list of names is published each year by the Department of Ecology which lists the level of threat posed by the plants and the legal responsibilities of owners who find them growing on their properties. Invidual counties may modify the list to fit specific distributions within the county.

Nutrient: Any chemical element, ion, or compound required by an organism for growth and reproduction.

Oligotrophic: Waters that are nutrient poor and which, as a result, have little algal production.

pH: The negative logarithm of the hydrogen ion concentration in a solution. This is a measure of acidity.

Pheophytin: A pigment resulting from the degradation of chlorophyll *a*, usually found in algal remains, suspended organic matter, or bottom sediments.

Phosphorus: One of the elements essential for growth and reproduction. Phosphorus is often the limiting or least available nutrient for plant growth in temperate freshwater ecosystems. The primary original source of phosphorus is from the earth in the form of phosphate rocks.

Photic Zone: The volume of water in a lake bounded by the depth to which light penetrates enough to enable plants to carry out photosynthesis.

Photosynthesis: The production of organic matter (carbohydrates) from inorganic carbon and water, utilizing the energy of light.

Phytoplankton: Free floating microscopic organisms that photosynthesize (algae and cyanobacteria).

Productivity: The production and accumulation of organic matter, usually measured over a certain period of time.

Residence Time: The average length of time that water or a chemical within the water, such as phosphate, remains in a lake.

Secchi Disk: A 20-cm (8-inch) diameter disk painted white and black in alternating quadrants. It is used to measure the transparency of the water in lakes.

Sediment: Solid material deposited in the bottom of a lake over time.

Stratification: The separation of water into nearly discrete layers caused by differences in temperature and subsequent water density differences.

Thermocline: The zone of rapid temperature decrease in a vertical section of lake water. (See metalimnion.)

Transparency: Water clarity of a lake as measured with a Secchi disk.

Trophic State: A term used to describe the productivity of a lake ecosystem classifying it as one of three increasing categories based on algal biomass: oligotrophic, mesotrophic, or eutrophic.

Turbidity: Cloudiness in water caused by the suspension of tiny particles (algae or detritus).

Turnover: The mixing of lake water from top to bottom after a period of stable stratification. This typically occurs in fall and is caused by wind and seasonal cooling of surface waters.

Van Dorn: A water sampling device that allows collection of a water sample from a desired depth without contaminating the sample with water from other depths.

Watershed: The geographical area that contributes surface and groundwater flow to a stream, lake, or other body of water. This can also be referred to as the “catchment basin” or “drainage basin.”

Watershed Management: The planning and carrying out of actions, legal requirements and protective measures taken by agencies and citizens to preserve and enhance the natural resources of a drainage basin for the production and protection of water supplies and water-based resources.

Water Year (WY): A division of the earth year based on generally perceived wet and dry periods rather than by calendar months. The U.S. Geological Survey uses the water year of October 1 through September 30 for data analysis.

Zooplankton: Small animals found in the water of lakes that possess limited powers of locomotion, and which feed on bacteria, algae, smaller animals, and organic detritus present in the water.